FRICTION FACTORS FOR VEGETATED WATERWAYS OF SMALL SLOPE

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FRICTION FACTORS FOR VEGETATED WATERWAYS OF SMALL SLOPE

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ABSTRACT

Experiments were conducted over a 4-year period to determine the friction factors (Manning *n*) for vegetated waterways of small slope. The plants used were wheat planted in 7-inch and 14-inch rows parallel to the flow, wheat in 7-inch rows perpendicular to the flow, sorghum and cotton in 40-inch rows parallel to the flow, sorghum in 20-inch rows parallel to the flow, and sudangrass, lespedeza, and lovegrass broadcast planted in the channels. For the poor-quality stands of wheat there was little or no difference in the *n* value for the 7-inch and 14-inch rows, but for the good-quality stands the *n* values for the 7-inch row spacing were considerably larger than those for the 14-inch row spacing. For the higher flows, which submerged the vegetation, row direction had no effect on the friction factor, but there was a large difference in the *n* values for the lower flows. A comparison of the *n* values at a hydraulic radius of 0.8 foot shows a value of 0.2 for the parallel rows and 0.4 for the perpendicular rows. For the 'Hegari' sorghum in 20-inch and 40-inch rows there was a difference in the *n* values for the low flows, with the wider row spacing having the lower value, but when the flow reached a hydraulic radius of about 1.5 feet, there was no difference in the *n* values for the two row spacings. The values of *n* for the test channel can serve as a base value to which corrections must be applied to adjust for the differences between the test channel and the channel for which an estimate of *n* is needed. Because of the lack of test data, adjustments involving the effect of each variable that influences the *n* value must be based on judgment.

KEYWORDS: friction factors (Manning *n*), plant density and quality, row spacing, row direction, small-slope channels, terrace-channel design, vegetated waterways.

INTRODUCTION

Experiments were conducted over a 4-year period to determine the friction factors for earth channels of small slope planted to wheat, cotton, sorghum, lespedeza, or grasses. The friction-factor data were intended for application to the design of diversion terraces. However, the data can be applied to the design of any terrace, or they can be used to estimate the depth of flow over flood plains planted to the types of vegetation tested. Proper choice of the friction factor is particularly important in the design of a terrace system. Each terrace must have adequate capacity because if it overtops, it will send added flow into the next

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terrace channel downslope, and it too may overtop and fail. This "domino effect" may continue until the lowest terrace in the tier is reached. Thus, the integrity of an entire system of terraces is dependent upon the adequacy of each terrace. Adequate capacity stems from good design, and good design in turn requires the selection of the correct value for the friction factor. This selection is made from reported values of friction factors obtained from experiments like those presented in this report.

The modern, broad-base terrace has been in use since 1885, when it was introduced by Priestly H. Mangum of North Carolina. It is difficult to imagine that, after 90 years, research on terraces should still be needed. However, as with nearly everything that man uses or constructs, improvements are sought and changes are made to meet new conditions—so it is with terraces. Today, larger terraces with greater channel capacity are required as a result of increased terrace spacing and length. Therefore, to avoid costly overdesign or ruinous underdesign, more careful attention is being given to the hydraulics of terrace channels, especially to the friction factor when a channel is choked with growing crops or other vegetation. Friction-factor values for this condition were not available, and those obtained from experiments on grass waterways of steep slope are probably not applicable to the small-slope terrace, particularly one planted to row crops parallel to the flow. The friction factor for this latter condition is possibly not as high as estimated, so experiments were run to determine the friction factors for small-slope channels planted to crops in rows parallel to the flow. These crops included wheat, cotton, and sorghum. Later, when it was realized that data of the kind being obtained would also be applicable to flood plains where the vegetation would not necessarily be in rows parallel to the flow, experiments were run on wheat in rows perpendicular to the flow direction and on two randomly distributed grasses and legumes.

This report describes the test channels, channel vegetation, instrumentation, and test procedures and gives the results of the experiments. Some discussion of the results is provided to supply some guidance for their use. A brief discussion of the method currently employed to estimate waterway capacity is given at the outset.

WATERWAY CAPACITY

The capacity of a waterway is the flow rate that can be conveyed without exceeding a safe depth in the waterway. Capacity is expressed in cubic feet per second and is calculated by the formula

$$Q = AV, \qquad (1)$$

where Q=flow rate (cubic feet per second),
A=cross-sectional area of the waterway (square feet),
and V=mean velocity of flow (feet per second).

Velocity is usually estimated by the Manning formula,

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}, \qquad (2)$$

where R=hydraulic radius, or area/wetted perimeter (feet),
S=energy gradient, or slope of waterway for normal flow (feet per foot),
and n=Manning n friction factor, or coefficient of roughness.

The dimensions R and S are functions of the geometry of the waterway and can be determined or constructed within the desired degree of accuracy. The Manning n values, however, must be estimated by comparing the channel for which a value is needed with other channels for which n is known, as determined by experiment. It is assumed that if the channel linings are similar, the friction factors are similar. This is a fairly safe assumption for hard-surfaced channels, but it is likely to result in considerable error in the case of vegetation-lined waterways. It has been stated that estimating flow in vegetation-lined channels is an art and not a science. Yet, for certain grass-lined waterways the prediction of flow is becoming more exact as the relationship between the friction factor and the physical characteristics of the vegetation are better defined. For example, the Soil Conservation Service handbook[3] relates the flow retardance class of a vegetal channel lin-

[3] Handbook of channel design for soil and water conservation. 1954. U.S. Dep. Agric., Soil Conserv. Serv. [Rep.] SCS-TP-61, 34 pp.

ing to the length and density of the vegetation in the channel. The flow retardance class is based on the relationship of the friction factor (n) to the product of the flow velocity (V) and hydraulic radius (R); this is the n–VR design method. Before this design method could be worked out a large amount of data and considerable study were required. A similar generalization cannot be developed for the channels in this study because not enough data are available. This report, therefore, mainly presents descriptions and photographs of the experimental waterways and gives the corresponding n values.

TEST CHANNELS

Two channels, FC 29 and FC 30, were constructed on a grade contour to hold earthwork to a minimum. Therefore, they include a reverse curve and a tangent reach. Figure 1 is a plan of the channels, showing three 150-foot reaches. The slope of the 600-foot channels was 0.1 percent. The cross section was trapezoidal, with a bottom width of 20 feet and side slopes of 1:1¼. The very steep side slope was used to approximate a rectangular cross section. Depths of the two channels were 3 and 4.25 feet. The soil was subsoil clay, so it was chiseled, mulched, manured, and fertilized.

Some good crops were produced in these waterways even though the soil was poor. The channels were prepared and seeded in accordance with the requirements of the crop. Wheat was planted in the fall for early summer tests. Immediately after the wheat tests the channels were reworked and planted to a summer crop. The flow tests were run after the crop had reached maximum growth, when the friction factor was at its maximum value.

INSTRUMENTATION AND PROCEDURES

Ten cross-section stations (50 feet apart) were established across each channel, with the first at station 1+00 and the last at station 5+50. The lines of these sections were at right angles to the channel centerline. A line occurring in a curve was placed perpendicular to the tangent to the curve. The cross section was marked by 2- by 4-inch stakes that were treated to resist decay. A galvanized sixteenpenny nail was driven into the top of the reference stake, which was set at a measured distance from the channel centerline. A piano wire was stretched from stake to stake across the channel and was marked with solder at 1-foot intervals, with a double mark at the 5-foot points and a triple mark at the 10-foot points. The wire was spring loaded for tautness but was not leveled because its only purpose was to locate the points across the channel where bottom readings were to be taken.

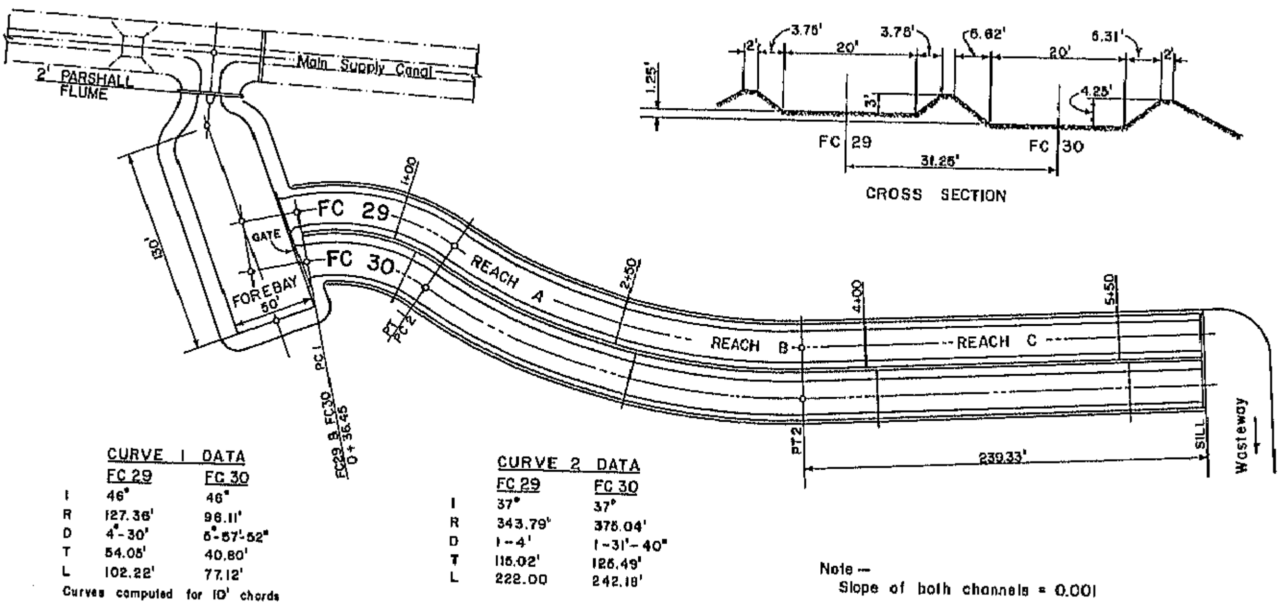

FIGURE 1.—Plan of test channels and forebay.

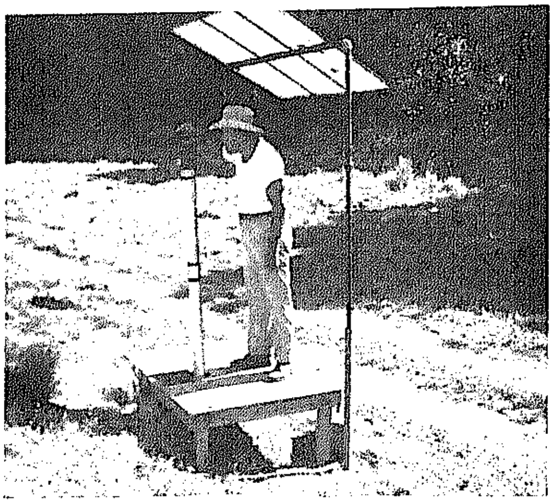

FIGURE 2.—Engineer's level mounted on fixed-pipe unipod. (Upper 2-ft section of pipe can be removed to lower instrument.)

FIGURE 3.—Outlet of channel FC 29 during flow of 31.8 ft³/s with the end sill in place, experiment 2. (Top of sill is 0.8 ft above channel grade at outlet.)

The cross sections were taken with an engineer's level and a level rod. Readings were to the nearest 0.01 foot at 1-foot intervals across the section. Two levels were used, one at each of the outside quarter points of the channel length. A permanent bench mark was set halfway along the channel and far enough outside to prevent its being affected by the channel water. Refinements were added as the experiments progressed. For the last 2 years of the experiments the instrument tripods were replaced by 4-inch-pipe unipods set in concrete. A platform was placed around each unipod to provide a level surface to stand upon, and a sunshade shaded the instrument and reduced the amount of releveling that otherwise would have been required (fig. 2). The cross sections of the channel were measured before each experiment, several times during the experiment (as needed), and after the experiment.

Flows up to 35 ft³/s were measured with a modified 2-foot Parshall flume (without throat or recovery sections) at the entrance to the forebay of the channels. This flume had been previously calibrated in place with a 3-foot H-flume installed in tandem with it. Flows greater than 35 ft³/s were measured with the main weir at the siphon outlet 1,200 feet upstream. The flow measurement at the weir was corrected for losses occurring in the conveyance canal. The accuracy of the flow measurements is estimated to be ±5 percent.

Before each test an end sill was placed at the outlet of the channel to control the water-surface slope. Figure 3 is a view of the outlet of channel FC 29 during a flow with the sill in place. Without the sill a drawdown curve (M2 profile) would have extended some distance upstream. For the larger flows this effect would have reached the head of the channel. A sill of proper height at the outlet provides a uniform flow depth in the channel. Since the height of the end sill depended on the unknown value of Manning *n*, the height had to be estimated, which was usually satisfactory. However, after the first four experiments three sill heights were used for each flow rate, with the first sill too low, the second just right, and the third too high (by estimate). It was hoped that the correct sill height could then be bracketed and that the friction factor for uniform flow could be determined by interpolation. The effect of an end sill on the water-surface profile is shown in figure 4. After each flow was released into the channel (and became steady), the water-surface elevations were measured. The steadiness of the flow was determined by water-level recorders placed at each end of the channel.

The water-surface elevations were measured with an engineer's level and point-ended level rods supported by a frame that provided for controlled vertical motion. Two rodmen, one at the water's edge on each side of the channel, made the measurements. An observer and a recorder completed the team. Observations were

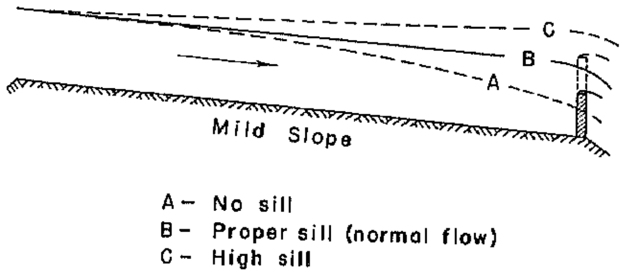

FIGURE 4.—Water-surface profiles in a mild-slope channel for three outlet conditions.

begun at the uppermost station, with the observer at the upstream instrument. When the rodmen reached the midpoint of the channel, the observer moved to the downstream instrument to observe the stations in that half of the channel. Thus, no shot was much over 125 feet, and the rod could be read directly to the nearest 0.001 foot. Four stations, which divided the channel into three 150-foot reaches, were selected for measuring slope. Ten rod readings were made in rapid succession, each to the nearest 0.001 foot. All measurements were recorded, and the average was used to compute the mean water-surface elevation. After the run downstream the observer and the recorder changed places, and observations were again made at the four stations, this time proceeding upstream. Water-surface elevations were measured at the six intermediate stations only during the first trip. Readings were taken to the nearest 0.01 foot for these stations, and the average value of at least three readings was recorded. This procedure was sufficiently accurate for determining the cross-sectional area.

During each flow test the locations of the water's edges at each cross section were determined. This measurement provided the top width needed in the calculation of cross-sectional areas and wetted perimeters and eliminated the need for plotting the cross sections.

The density and height of the vegetation in each channel were measured. The measurement system used depended upon the kind of vegetation. The crops in rows were described by the number of rows across the section and by the number of stems or plants per foot of row. Randomly distributed plant patterns (produced by broadcast planting) were described by counting the number of stems per unit area.

A series of flows was run on each channel, starting with a flow depth of approximately 0.5 foot and working upward by increments until the maximum capacity of the channel was reached. The number of flows for a single channel experiment ranged from 9 to 26 and sometimes extended over a 1-week period. If, in this time the vegetation grew significantly, it was measured again at the conclusion of the tests. The percentage of plants submerged during the flows was estimated and is reported in the tables under "Results and Discussion."

The experiments were conducted with two crops in each of the two channels per year. The spring crop was always wheat, but other crops were used in the summer. Table 1 lists the experiments and gives brief data on each crop. A more detailed description of each crop, as it appeared at the time of the tests, is given under "Results and Discussion."

CALCULATIONS

The mean velocity (V) for each reach was calculated by dividing the discharge rate (Q) by a weighted-average area for the reach. Four cross sections (50-foot stations) were used for determining the average area for the reach, and the two end stations were assigned half the weight of each of the two interior stations. The station mean velocities were calculated for the ends of each reach for use in velocity-head determinations. The hydraulic radius (R) was calculated by dividing the weighted-average area for the reach by the weighted-average wetted perimeter. The slope (S) was calculated by dividing the difference in the total energy at the ends of the reach by the length of the reach (150 feet). The total energy was calculated by adding the velocity head at the station to the water-surface elevation. The averaging used in these calculations was permissible because the differences between the various quantities averaged was usually small.

The friction factor (Manning n) was calculated for each test by substituting the measured and computed values of V, R, and S into Manning's formula (equation 2) and solving for n. Separate calculations were made for each of the reaches in the 450-foot test portion of the channel. The three values were averaged to yield a single value for each of the hydraulic factors for each test. This averaging tended to

TABLE 1.—*Data on plants tested for each experiment*

Experiment and test channel	Row spacing (inches)	Row direction or relation to flow	Cover quality	Average plant height (inches)	Plant density: Stems per ft of row	Plant density: Stems per ft²
			Wheat			
Experiment 1:						
FC 29	7	Parallel	Good	26	31	...
FC 30	7	... do	do	28	26	...
Experiment 3:						
FC 29	14	... do	Poor	24	50	...
FC 30	7	... do	do	23	35	...
Experiment 5:						
FC 29	7	... do	Excellent	28	68	...
FC 30	7	Perpend.	do	30	79	...
Experiment 7:						
FC 29	14	Parallel	Very good	28	73	...
FC 30	7	... do	do	36	52	...
			Sorghum			
Experiment 2:						
FC 29	40	Parallel	Very good	43	2.3	...
FC 30	40	... do	do	58	4.2	...
Experiment 4: FC 30	20	... do	Good	58	2.0	...
			Cotton			
Experiment 4: FC 29	40	Parallel	Poor	21	1.2	...
Experiment 6: FC 29	40	... do	Very good	34	2.4	...
			Sudangrass			
Experiment 6: FC 30	(1)	(1)	Very good	47	...	53
			Lespedeza			
Experiment 8: FC 29	(1)	(1)	Very good	8	...	122
			Lovegrass and crabgrass			
Experiment 8: FC 30	(1)	(1)	Good	16	...	165

[1] Seed were broadcast.

oversimplify the results, but it was done to reduce the great amount of data to manageable quantities.

The major hydraulic elements are given in the tables under "Results and Discussion." The top width is not shown, but if this dimension is needed, an approximate value (within 3 percent) can be obtained from the theoretical relationship for the cross section; thus, top width$=0.78P+4.37$, where P=wetted perimeter in feet.

RESULTS AND DISCUSSION

The Manning n value did not remain constant for a given channel but varied with the discharge, with the largest value of n for some crops being three times the smallest value. One of the channels showed a fivefold change in n over the range of discharges used. This nonconstant character of the coefficient has been observed before and is not a new discovery. Earlier studies by the laboratory showed that, for submerged grasses, the value of the friction factor is related to the product of velocity and hydraulic radius (VR). This relationship is characteristic of the vegetation and is influenced mainly by the length of the vegetation and partly by the density. This finding led to the establishment of five experimental n–VR

curves for five different degrees of vegetal retardance, according to the "Handbook of Channel Design for Soil and Water Conservation" (cited in footnote 3). The curves for vegetal retardance classes A, B, C, and D are shown on each *n–VR* plot to provide a standard of comparison for these experiments.

For these experiments the *n–VR* criterion was applicable only when the vegetation was submerged. When the vegetation remained upright and was not disturbed by the flow, the *n* value bore no consistent relationship to *VR*. In this case an *n*-hydraulic-radius plotting better portrayed the variation of *n* with the flow. Therefore, one curve or the other (*n–VR* or *n*-hydraulic radius) was used to show the relationship between the friction factor and a hydraulic property of the channel, the choice depending on which seemed to be more appropriate.

The results of the experiments are presented according to vegetation, starting with wheat. Photographs and a brief description of the vegetation are given, and a tabulation of the hydraulic elements and a plotting of the flow-retardance values versus either hydraulic radius or *VR* are included.

Experiment 1

Wheat in channel FC 29

The wheat was drilled in 7-inch rows running lengthwise in the channel. When the tests were begun, the wheat was ripe, and most of the leaves were brown and dry. The stand varied along the channel, with the greatest density and tallest stems occurring at the downstream end. Table 2 gives the stand counts and stem heights, and figure 5 shows a portion of the center reach before the tests.

FIGURE 5.—Wheat in reach B of channel FC 29 before tests, experiment 1.

TABLE 2.—*Stand counts and stem heights for wheat in channel FC 29, experiment 1*

Reach[1]	No. rows	No. stems per foot of row	Average stem height (inches)	Average tallest stem[2] (inches)
A	34	24	24	36
B	34	34	25	36
C	33	34	30	40
Average for channel	34	31	26	37

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest stem was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest stem."

Ten flow tests were run in increasing order of magnitude. Only one sill height was used at the channel outlet for each flow rate. Two of the tests were repeat tests (5A and 6A). During test 6 the flow through the 2-foot Parshall flume seemed unduly disturbed by the poor approach. Testing was halted after this test, and the approach was improved upon. Training walls were added to direct the flow toward the flume, and a curved entrance and upward-sloping ramp were placed at the junction of the flume and training walls. This configuration, which eliminated the undesirable standing wave in the flume, was used for all subsequent tests. Tests 5 and 6 are not reported because the discharge measurement is believed to be wrong. The hydraulic data and friction factors for the experiment are given in table 3. The Manning *n* values for these flow tests versus the corresponding *VR* values are plotted in figure 6. The curve approaches the standard class B retardance curve at the higher flows.

(Continued on page 11.)

TABLE 3. — *Hydraulic elements and friction factors for experiment 1, wheat in channel FC 29*
[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	3.36	12.1	0.28	21.9	0.552	0.00131	73	10.3	0.131	0.089	0.153	0
B	3.36	12.5	.27	21.7	.575	.00120	73	10.2	.133	.091	.155	0
C	3.36	11.6	.29	21.6	.536	.00185	73	9.17	.146	.097	.155	0
Average	...	...	...	...	.554	......	...	9.89	.137	.092	.154	...
Test 2:												
Reach A	5.38	18.3	0.29	22.9	0.801	0.00127	73	9.21	0.156	0.112	0.235	0
B	5.38	18.5	.29	22.6	.818	.00124	73	9.10	.158	.115	.237	0
C	5.38	17.4	.31	22.6	.768	.00173	73	8.47	.167	.119	.237	0
Average	...	...	...	...	.796	......	...	8.93	.160	.115	.236	...
Test 3:												
Reach A	8.83	25.4	0.35	24.0	1.06	0.00137	73	9.13	0.165	0.126	0.369	0
B	8.83	25.2	.35	23.7	1.07	.00139	73	9.07	.167	.127	.374	0
C	8.83	23.2	.38	23.5	.99	.00213	73	8.30	.179	.134	.376	0
Average	...	...	...	...	1.04	......	...	8.83	.170	.129	.373	...
Test 4:												
Reach A	15.8	35.9	0.44	25.5	1.41	0.00143	73	9.82	0.161	0.132	0.622	15
B	15.8	35.1	.45	25.1	1.40	.00147	73	9.91	.160	.130	.630	5
C	15.8	32.6	.49	24.8	1.31	.00222	73	9.01	.174	.139	.637	1
Average	...	...	...	...	1.37	......	...	9.58	.165	.134	.630	...
Test 5A:												
Reach A	19.7	40.0	0.49	26.1	1.53	0.00138	75	10.7	0.150	0.125	0.754	20
B	19.7	39.8	.50	25.8	1.54	.00143	75	10.5	.152	.128	.762	10
C	19.7	37.7	.52	25.8	1.46	.00207	75	9.51	.168	.138	.764	2
Average	...	...	...	...	1.51	......	...	10.2	.157	.130	.760	...
Test 6A:												
Reach A	22.5	43.7	0.51	26.6	1.64	0.00131	75	11.1	0.146	0.124	0.843	70
B	22.5	44.2	.51	26.4	1.68	.00136	75	10.6	.153	.131	.855	45
C	22.5	42.5	.53	26.2	1.62	.00190	75	9.53	.170	.143	.857	20
Average	...	...	...	...	1.65	......	...	10.4	.156	.133	.852	...
Test 7:												
Reach A	25.4	46.7	0.54	27.0	1.73	0.00123	75	11.8	0.138	0.120	0.943	90
B	25.4	47.3	.54	26.8	1.76	.00126	75	11.4	.144	.125	.947	85
C	25.4	45.9	.55	26.7	1.72	.00180	75	9.94	.165	.141	.953	65
Average	...	...	...	...	1.74	......	...	11.0	.149	.129	.948	...
Test 8:												
Reach A	30.8	51.5	0.60	27.7	1.86	0.00116	76	12.8	0.129	0.114	1.11	95
B	30.8	52.3	.59	27.5	1.90	.00113	76	12.7	.132	.116	1.12	95
C	30.8	51.5	.59	27.5	1.87	.00167	76	10.7	.156	.136	1.11	90
Average	...	...	...	...	1.88	......	...	12.1	.139	.122	1.11	...

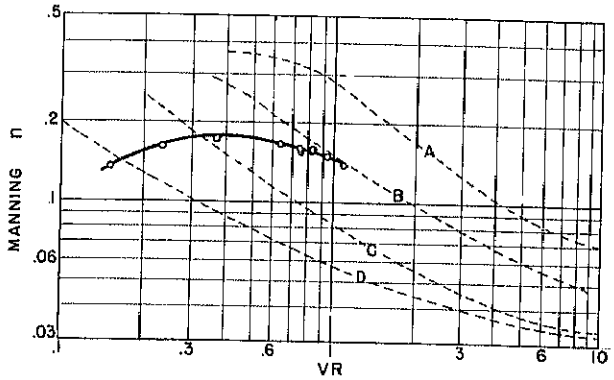

FIGURE 6.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 29, experiment 1.

FIGURE 7.—Wheat in reach A of channel FC 30 before tests, experiment 1.

TABLE 4.—*Stand counts and stem heights for wheat in channel FC 30, experiment 1*

Reach[1]	No. rows	No. stems per foot of row	Average stem height (inches)	Average tallest stem[2] (inches)
A	33	25	25	36
B	33	28	29	36
C	32	26	30	37
Average for channel	33	26	28	36

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest stem was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest stem."

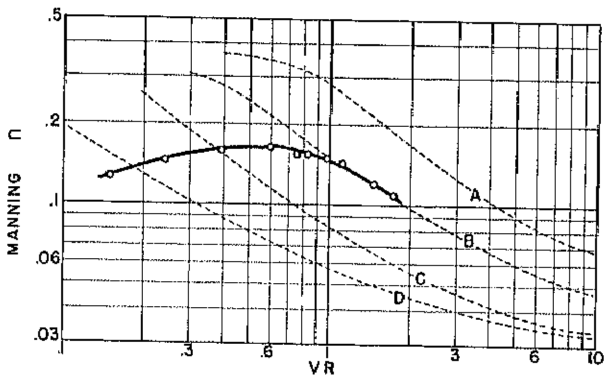

FIGURE 8.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 30, experiment 1.

TABLE 5. — *Hydraulic elements and friction factors for experiment 1, wheat in channel FC 30*

[Q, Discharge, ft^3/s. A, Area, ft^2. V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	3.35	12.9	0.26	22.4	0.577	0.00114	79	10.1	0.134	0.092	0.149	0
B	3.35	12.6	.26	22.4	.564	.00105	79	10.9	.124	.085	.149	0
C	3.35	11.3	.30	22.2	.511	.00137	79	11.2	.119	.080	.151	0
Average	...	...	...	...	.551	......	...	10.7	.126	.086	.150	...
Test 2:												
Reach A	5.64	19.2	0.29	23.3	0.823	0.00121	79	9.31	0.155	0.112	0.242	0
B	5.64	18.6	.30	23.4	.796	.00119	79	9.84	.145	.106	.241	0
C	5.64	16.6	.34	23.0	.720	.00151	79	10.3	.137	.098	.245	0
Average	...	...	...	...	.780	......	...	9.82	.146	.105	.243	...

TABLE 5. — *Hydraulic elements and friction factors for experiment 1, wheat in channel FC 30* — Continued

[*Q*, Discharge, ft^3/s. *A*, Area, ft^2. *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	*Q*	*A*	*V*	*P*	*R*	*S*	°F	*C*	*n*	n_k	*VR*	%
Test 3:												
Reach A	9.54	27.0	0.35	24.6	1.10	0.00129	79	9.40	0.162	0.125	0.389	0
B	9.54	25.7	.37	24.5	1.05	.00147	79	9.47	.159	.122	.391	0
C	9.54	22.5	.42	23.8	.94	.00193	79	9.96	.148	.112	.401	0
Average	...	...	...	...	1.03	......	...	9.61	.156	.120	.394	...
Test 4:												
Reach A	15.4	37.1	0.41	26.0	1.43	0.00130	79	9.59	0.165	0.135	0.592	5
B	15.4	35.5	.43	25.7	1.38	.00153	79	9.42	.167	.136	.598	1
C	15.4	31.8	.48	25.2	1.27	.00186	79	9.92	.157	.125	.612	1
Average	...	...	...	...	1.36	......	...	9.64	.163	.132	.601	...
Test 5:												
Reach A	19.5	40.6	0.48	26.0	1.56	0.00137	78	10.4	0.156	0.130	0.747	40
B	19.5	38.5	.50	25.7	1.50	.00165	78	10.1	.157	.132	.758	5
C	19.5	34.5	.56	25.5	1.35	.00195	78	11.0	.143	.117	.761	2
Average	...	...	...	...	1.47	......	...	10.5	.152	.127	.755	...
Test 6:												
Reach A	22.0	43.8	0.50	26.8	1.63	0.00140	78	10.6	0.154	0.130	0.822	65
B	22.0	41.9	.53	26.5	1.58	.00168	78	10.2	.158	.133	.833	30
C	22.0	37.6	.59	25.9	1.45	.00197	78	11.0	.146	.120	.850	5
Average	...	...	...	...	1.55	......	...	10.6	.153	.128	.835	...
Test 7:												
Reach A	26.6	48.6	0.55	27.5	1.77	0.00129	78	11.4	0.144	0.125	0.968	90
B	26.6	47.1	.56	27.4	1.72	.00163	78	10.6	.154	.132	.970	60
C	26.6	42.9	.62	26.6	1.61	.00188	78	11.3	.144	.122	.998	25
Average	...	...	...	...	1.70	......	...	11.1	.147	.126	.979	...
Test 8:												
Reach A	30.6	52.1	0.59	28.0	1.86	0.00125	77	12.1	0.137	0.120	1.09	95
B	30.6	50.7	.60	27.7	1.83	.00159	77	11.2	.147	.129	1.10	85
C	30.6	46.2	.66	27.1	1.70	.00189	77	11.7	.139	.120	1.13	70
Average	...	...	...	...	1.80	......	...	11.7	.141	.123	1.11	...
Test 9:												
Reach A	41.2	57.3	0.72	28.7	2.00	0.00121	77	14.6	0.115	0.103	1.43	100
B	41.2	55.8	.74	28.5	1.96	.00155	77	13.4	.126	.111	1.45	95
C	41.2	51.8	.80	27.7	1.87	.00178	77	13.8	.121	.106	1.48	95
Average	...	...	...	...	1.94	......	...	14.0	.121	.107	1.45	...
Test 10:												
Reach A	50.4	60.8	0.83	29.2	2.08	0.00128	78	16.1	0.105	0.095	1.72	100
B	50.4	59.2	.85	28.9	2.05	.00162	78	14.8	.115	.103	1.74	100
C	50.4	54.6	.92	28.1	1.94	.00182	78	15.6	.108	.096	1.79	100
Average	...	...	...	...	2.02	......	...	15.5	.109	.098	1.75	...

Wheat in channel FC 30

The wheat was drilled in 7-inch rows. When the tests were begun, the wheat was ripe, and most of the leaves were brown and dry. Table 4 gives the stand counts and stem heights, and figure 7 shows reach A before the tests.

Ten flow tests, ranging from 3.3 to 50.4 ft^3/s, were run in increasing order of magnitude. One sill height at the channel outlet was used for each flow. The hydraulic data and friction factors for the tests are given in table 5. The Manning n values for the tests versus the corresponding values of VR are plotted in figure 8. The curve for the larger values of VR coincides with the standard class B retardance curve.

Experiment 3

Wheat in channel FC 29

The wheat was drilled in 14-inch rows running lengthwise in the channel. When the tests were begun, the wheat was starting to ripen. About 50 percent of it had turned color, but the rest was still lush and green. The base leaves on all plants had dried, leaving practically no foliage at the base. Table 6 gives the stand counts and stem heights.

A view of reach B during test 3 (flow of 4.1 ft^3/s) is shown in figure 9. Typical plants from the channel are shown in figure 10.

Fourteen flow tests, ranging from 4.1 to 40.0 ft^3/s, were run in increasing order of magnitude. Three sill heights were used at the

TABLE 6.—*Stand counts and stem heights for wheat in channel FC 29, experiment 3*

Reach[1]	No. rows	No. stems per foot of row	Average stem height (inches)	Average tallest stem[2] (inches)
A	18	48	24	29
B	18	50	24	36
C	18	52	24	29
Average for channel	18	50	24	31

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest stem was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest stem."

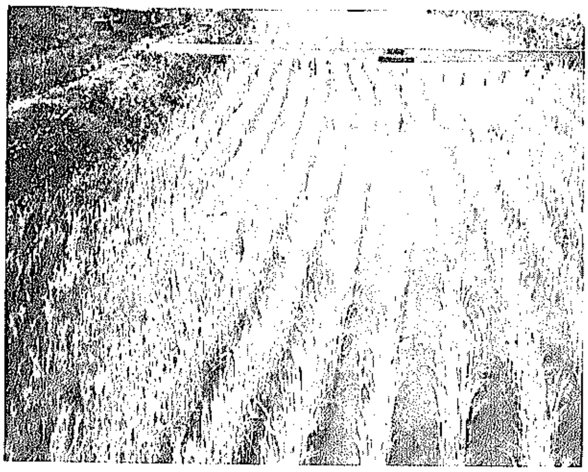

FIGURE 9.—Wheat in reach B of channel FC 29 during flow of 4.1 ft^3/s with depth of about 8 inches, experiment 3.

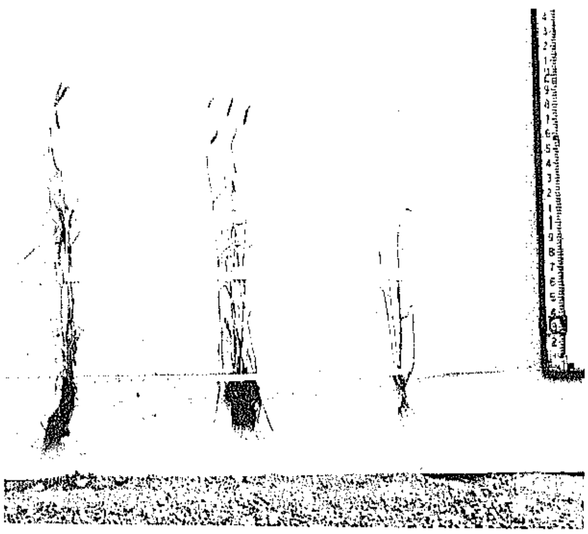

FIGURE 10.—Typical wheat plants in same relative positions occupied in channel FC 29, experiment 3.

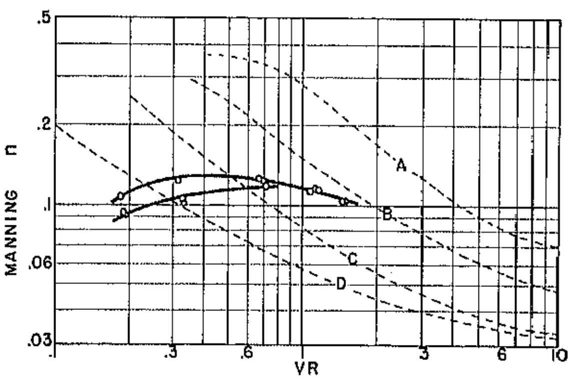

FIGURE 11.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 29, experiment 3.

TABLE 7.—*Hydraulic elements and friction factors for experiment 3, wheat in channel FC 29*

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	4.10	11.2	0.37	21.7	0.515	0.00127	73	14.3	0.093	0.065	0.189	0
B	4.10	10.7	.38	21.5	.499	.00146	73	14.1	.094	.066	.191	0
C	4.10	9.39	.44	21.2	.443	.00176	73	15.6	.083	.058	.193	0
Average	...	...	...	...	.486	......	...	14.7	.090	.063	.191	...
Test 2:												
Reach A	4.13	11.4	0.36	21.8	0.522	0.00127	75	14.1	0.095	0.067	0.189	0
B	4.13	10.9	.38	21.5	.508	.00146	75	13.9	.096	.067	.192	0
C	4.13	9.92	.42	21.3	.465	.00159	75	15.3	.086	.060	.193	0
Average	...	...	...	...	.498	......	...	14.4	.092	.065	.191	...
Test 3:												
Reach A	4.14	13.6	0.30	22.3	0.613	0.000800	73	13.7	0.101	0.072	0.186	0
B	4.14	15.2	.27	22.4	.676	.000667	73	12.8	.108	.079	.185	0
C	4.14	17.0	.24	22.7	.747	.000467	73	13.1	.108	.079	.182	0
Average	...	...	...	...	.679	......	...	13.2	.106	.077	.184	...
Test 4:												
Reach A	7.48	17.1	0.44	22.8	0.747	0.00137	73	13.7	0.104	0.077	0.327	0
B	7.48	16.1	.46	22.6	.714	.00166	73	13.5	.104	.077	.332	0
C	7.48	13.8	.54	22.3	.620	.00209	73	15.0	.091	.067	.335	0
Average	...	...	...	...	.694	......	...	14.1	.100	.074	.331	...
Test 5:												
Reach A	7.49	18.0	0.42	23.0	0.780	0.00119	73	13.7	0.104	0.078	0.325	0
B	7.49	17.8	.42	22.8	.780	.00133	73	13.1	.109	.081	.328	0
C	7.49	17.2	.44	22.8	.752	.00133	73	13.8	.103	.077	.330	0
Average	...	...	...	...	.771	......	...	13.5	.105	.079	.328	...
Test 6:												
Reach A	7.49	22.0	0.34	23.7	0.930	0.000867	73	12.0	0.123	0.094	0.316	0
B	7.49	23.3	.32	23.6	.986	.000700	73	12.2	.122	.094	.317	0
C	7.49	23.5	.30	24.2	1.04	.000540	73	12.5	.119	.094	.309	0
Average	...	...	...	...	.985	......	...	12.2	.121	.094	.314	...
Test 7:												
Reach A	17.4	30.6	0.57	24.9	1.23	0.00163	75	12.7	0.122	0.099	0.700	1
B	17.4	28.2	.62	24.4	1.16	.00202	75	12.7	.121	.097	.715	1
C	17.4	24.5	.71	24.1	1.02	.00254	75	13.9	.107	.085	.723	1
Average	...	...	...	...	1.14	......	...	13.1	.117	.094	.713	...
Test 8:												
Reach A	17.4	32.6	0.54	25.3	1.29	0.00140	75	12.6	0.124	0.101	0.690	20
B	17.4	31.6	.55	24.9	1.27	.00156	75	12.4	.126	.102	.702	15
C	17.4	30.2	.58	24.9	1.21	.00163	75	13.0	.119	.096	.699	5
Average	...	...	...	...	1.26	......	...	12.7	.123	.100	.697	...
Test 9:												
Reach A	17.4	38.0	0.46	26.0	1.46	0.000867	75	12.9	0.124	0.103	0.670	55
B	17.4	38.9	.45	26.0	1.50	.00103	75	11.4	.141	.117	.674	55
C	17.4	39.7	.44	26.2	1.52	.000833	75	12.3	.129	.110	.667	55
Average	...	...	...	...	1.49	......	...	12.2	.131	.110	.670	...

TABLE 7. — *Hydraulic elements and friction factors for experiment 3, wheat in channel FC 29* — Continued

[*Q*, Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	*Q*	*A*	*V*	*P*	*R*	*S*	°F	*C*	*n*	n_k	*VR*	%
Test 10:												
Reach A	30.8	43.1	0.71	26.6	1.62	0.00153	73	14.3	0.113	0.098	1.16	98
B	30.8	40.9	.75	26.2	1.56	.00199	73	13.5	.119	.102	1.17	90
C	30.8	37.5	.82	25.9	1.45	.00213	73	14.8	.108	.091	1.19	85
Average	...	...	...	...	1.54	......	...	14.2	.113	.097	1.17	...
Test 11:												
Reach A	30.8	47.0	0.66	27.2	1.73	0.00119	73	14.4	0.113	0.099	1.13	98
B	30.8	46.7	.66	27.0	1.73	.00133	73	13.8	.119	.103	1.14	95
C	30.8	46.3	.67	27.1	1.71	.00123	73	14.5	.113	.098	1.14	95
Average	...	...	...	...	1.72	......	...	14.2	.115	.100	1.14	...
Test 12:												
Reach A	30.8	53.0	0.58	28.2	1.88	0.000800	73	15.0	0.111	0.098	1.09	100
B	30.8	54.2	.57	28.3	1.92	.000800	73	14.5	.115	.102	1.09	100
C	30.8	56.1	.55	28.5	1.97	.000700	73	14.8	.113	.101	1.08	100
Average	...	...	...	...	1.92	......	...	14.8	.113	.100	1.09	...
Test 13:												
Reach A	40.0	47.8	0.84	27.4	1.75	0.00149	75	16.4	0.099	0.088	1.46	100
B	40.0	45.5	.88	26.8	1.70	.00195	75	15.3	.109	.093	1.49	100
C	40.0	42.2	.95	26.6	1.59	.00218	75	16.1	.099	.087	1.50	100
Average	...	...	...	...	1.68	......	...	15.9	.102	.089	1.48	...
Test 14:												
Reach A	40.0	50.0	0.80	27.7	1.80	0.00136	75	16.1	0.101	0.091	1.44	100
B	40.0	48.5	.82	27.3	1.78	.00159	75	15.6	.105	.093	1.47	100
C	40.0	47.0	.85	27.2	1.73	.00159	75	16.2	.099	.089	1.47	100
Average	...	...	...	...	1.77	......	...	16.0	.102	.091	1.46	...

channel outlet for each discharge rate, except for the largest flow, for which only two sill heights were used. The hydraulic data and friction factors for the tests are given in table 7. The Manning *n* values for the tests are plotted against the corresponding values of *VR* in figure 11. The curve approaches the standard class B retardance for the larger flows. The spread of the *n* values for the lower *VR* values is attributed to the end-sill effect on flow depths and velocities. Two envelope curves encompass the *n* values.

Wheat in channel FC 30

The wheat was drilled in 7-inch rows. When the tests were begun, the wheat was ripe. Table 8 gives the stand counts and stem heights. Figure 12 shows reach A during a flow, and figure 13 shows typical plants from the channel.

(Continued on page 16.)

TABLE 8.—*Stand counts and stem heights for wheat in channel FC 30, experiment 3*

Reach[1]	No. rows	No. stems per foot of row	Average stem height (inches)	Average tallest stem[2] (inches)
A	35	33	23	28
B	35	34	22	27
C	35	38	24	28
Average for channel	35	35	23	28

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest stem was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest stem."

TABLE 9. — *Hydraulic elements and friction factors for experiment 3, wheat in channel FC 30*

[*Q*, Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	*Q*	*A*	*V*	*P*	*R*	*S*	°F	*C*	*n*	n_k	*VR*	%
Test 1:												
Reach A	4.10	12.8	0.32	22.9	0.560	0.00143	77	11.3	0.120	0.082	0.179	0
B	4.10	12.8	.32	22.5	.570	.00109	77	12.8	.105	.074	.182	0
C	4.10	11.0	.37	22.2	.494	.00169	77	12.9	.102	.071	.185	0
Average	...	...	...	...	.541	......	...	12.3	.109	.076	.182	...
Test 2:												
Reach A	4.10	13.0	0.32	22.9	0.570	0.00136	77	11.3	0.120	0.083	0.180	0
B	4.10	13.0	.32	22.5	.577	.00113	77	12.3	.110	.077	.182	0
C	4.10	11.0	.37	22.3	.495	.00167	77	12.9	.102	.071	.184	0
Average	...	...	...	...	.547	......	...	12.2	.111	.077	.182	...
Test 3:												
Reach A	4.13	14.6	0.28	23.1	0.630	0.00107	77	10.9	0.126	0.089	0.178	0
B	4.13	15.8	.26	23.1	.683	.000720	77	11.8	.118	.085	.178	0
C	4.13	16.0	.26	23.2	.688	.000734	77	11.5	.121	.087	.178	0
Average	...	...	...	...	.667	......	...	11.4	.122	.087	.178	...
Test 4:												
Reach A	7.43	19.5	0.38	23.9	0.817	0.00151	73	10.8	0.134	0.098	0.310	0
B	7.43	19.0	.39	23.5	.807	.00143	73	11.5	.124	.093	.316	0
C	7.43	15.8	.47	23.1	.684	.00219	73	12.1	.115	.084	.321	0
Average	...	...	...	...	.769	......	...	11.5	.124	.092	.316	...
Test 5:												
Reach A	7.44	20.4	0.37	24.0	0.846	0.00140	73	10.7	0.136	0.100	0.310	0
B	7.44	20.3	.37	23.7	.856	.00125	73	11.2	.129	.097	.314	0
C	7.44	18.2	.41	23.5	.774	.00157	73	11.7	.122	.090	.316	0
Average	...	...	...	...	.825	......	...	11.2	.129	.096	.313	...
Test 6:												
Reach A	7.49	25.3	0.30	24.6	1.03	0.000894	73	9.75	0.153	0.117	0.305	0
B	7.49	27.3	.28	24.7	1.10	.000540	73	11.3	.134	.105	.303	0
C	7.49	28.0	.27	24.7	1.13	.000634	73	10.0	.152	.118	.303	0
Average	...	...	...	...	1.09	......	...	10.4	.146	.113	.304	...
Test 7:												
Reach A	17.3	33.7	0.51	25.8	1.30	0.00193	73	10.3	0.152	0.122	0.668	30
B	17.3	31.7	.55	25.5	1.25	.00172	73	11.8	.132	.106	.684	25
C	17.3	26.7	.65	24.7	1.08	.00270	73	12.0	.127	.099	.700	10
Average	...	...	...	...	1.21	......	...	11.4	.137	.109	.684	...
Test 8:												
Reach A	17.3	37.9	0.46	26.3	1.44	0.00138	73	10.2	0.155	0.128	0.656	75
B	17.3	38.0	.46	26.2	1.45	.00100	73	11.9	.134	.111	.660	75
C	17.3	36.6	.47	25.8	1.42	.00125	73	11.2	.142	.117	.668	55
Average	...	...	...	...	1.44	......	...	11.1	.144	.119	.661	...
Test 9:												
Reach A	17.3	46.2	0.37	27.6	1.68	0.000774	73	10.4	0.157	0.133	0.628	90
B	17.3	48.7	.36	27.8	1.75	.000480	73	12.2	.134	.116	.621	90
C	17.3	49.6	.35	27.6	1.79	.000533	73	11.2	.146	.127	.623	90
Average	...	...	...	...	1.74	......	...	11.3	.146	.125	.624	...

TABLE 9. — *Hydraulic elements and friction factors for experiment 3, wheat in channel FC 30* — Continued

[*Q*, Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 10:												
Reach A	30.0	44.1	0.68	27.2	1.62	0.00171	73	12.9	0.125	0.108	1.10	90
B	30.0	42.8	.70	27.0	1.59	.00140	73	14.8	.109	.094	1.11	90
C	30.0	39.4	.76	26.3	1.50	.00193	73	14.2	.114	.096	1.14	95
Average	...	...	...	...	1.57	......	...	14.0	.116	.099	1.12	...
Test 11:												
Reach A	30.0	50.6	0.59	28.1	1.80	0.00109	73	13.4	0.123	0.108	1.07	95
B	30.0	51.8	.58	28.3	1.83	.000787	73	15.3	.108	.096	1.06	90
C	30.0	51.3	.59	27.9	1.84	.000873	73	14.6	.113	.100	1.08	95
Average	...	...	...	...	1.82	......	...	14.4	.115	.101	1.07	...
Test 12:												
Reach A	30.0	61.6	0.49	29.6	2.08	0.000620	73	13.6	0.124	0.112	1.01	95
B	30.0	65.1	.46	30.0	2.17	.000333	73	17.2	.099	.090	1.00	95
C	30.0	66.0	.46	29.8	2.22	.000453	73	14.3	.118	.109	1.01	100
Average	...	...	...	...	2.16	......	...	15.0	.114	.104	1.01	...
Test 13:												
Reach A	44.5	50.5	0.88	28.1	1.79	0.00176	73	15.7	0.105	0.093	1.58	95
B	44.5	49.1	.91	28.1	1.75	.00141	73	18.2	.090	.080	1.59	95
C	44.5	45.8	.97	27.2	1.68	.00185	73	17.4	.094	.082	1.64	98
Average	...	...	...	...	1.74	......	...	17.1	.096	.085	1.60	...
Test 14:												
Reach A	44.4	57.8	0.77	29.2	1.98	0.00117	73	16.0	0.105	0.094	1.52	100
B	44.4	59.0	.75	29.2	2.02	.000800	73	18.6	.090	.082	1.52	100
C	44.4	58.2	.76	28.8	2.02	.000947	73	17.3	.097	.088	1.54	100
Average	...	...	...	...	2.01	......	...	17.3	.097	.088	1.53	...
Test 15:												
Reach A	44.3	69.9	0.63	30.8	2.27	0.000627	73	16.8	0.103	0.094	1.44	100
B	44.3	73.2	.61	31.2	2.34	.000413	73	19.5	.088	.082	1.42	100
C	44.3	73.7	.60	30.8	2.39	.000500	73	17.4	.099	.093	1.44	100
Average	...	...	...	...	2.33	......	...	17.9	.097	.090	1.43	...
Test 16:												
Reach A	75.6	60.9	1.24	29.6	2.06	0.00192	73	19.8	0.085	0.077	2.55	100
B	75.6	58.8	1.29	29.1	2.02	.00159	73	22.7	.074	.068	2.59	100
C	75.6	54.1	1.40	28.2	1.92	.00195	73	22.8	.073	.067	2.68	100
Average	...	...	...	...	2.00	......	...	21.8	.077	.071	2.61	...
Test 17:												
Reach A	75.6	73.8	1.02	31.3	2.36	0.00105	73	20.6	0.084	0.079	2.42	100
B	75.6	75.6	1.00	31.5	2.40	.000747	73	23.6	.073	.069	2.40	100
C	75.6	74.3	1.02	30.8	2.41	.000860	73	22.4	.077	.073	2.46	100
Average	...	...	...	...	2.39	......	...	22.2	.078	.074	2.43	...
Test 18:												
Reach A	75.6	86.8	0.87	32.8	2.64	0.000773	73	19.2	0.091	0.087	2.30	100

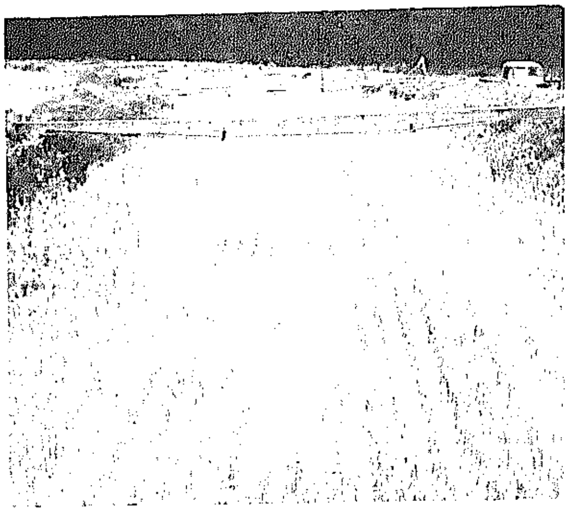

FIGURE 12.—Wheat in reach A of channel FC 30 during flow of 7.4 ft³/s with depth of about 10 inches, experiment 3.

Eighteen flow tests, ranging from 4.1 to 75.6 ft³/s, were run in increasing order of magnitude. Three sill heights were used for each discharge rate. No data were taken during test 18 on reaches B and C because the channel bank on the left side overtopped. The hydraulic elements and friction factors for the tests are given in table 9. The Manning n values for the tests are plotted against the corresponding values of VR in figure 14. The curve approaches the standard class B retardance curve.

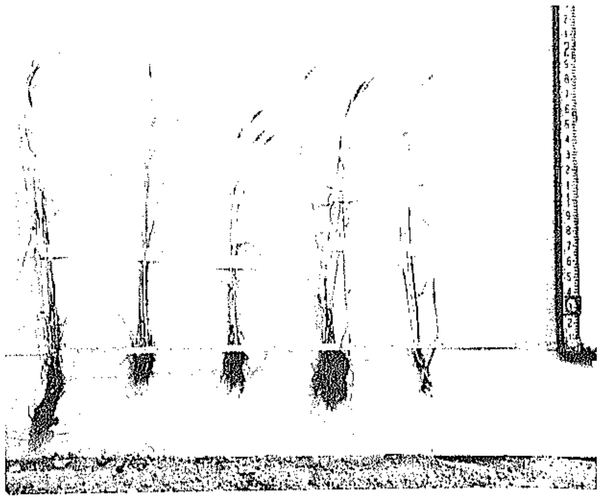

FIGURE 13.—Typical wheat plants in same relative positions occupied in channel FC 30, experiment 3.

Experiment 5

Wheat in channel FC 29

The wheat was drilled in 7-inch rows running lengthwise in the channel. When the tests were begun, the wheat was just starting to head out and had an average height of 26 inches. During the 8-day period of the tests, the wheat grew another 5 inches to an average height of 31 inches. Table 10 gives the stand counts and stem heights before and after the tests. Figure 15 shows reach B (the center reach) before the tests, and figure 16 shows the wheat in a cross section of the channel.

TABLE 10.—*Stand counts and stem heights for wheat before and after tests in channel FC 29, experiment 5*

Reach[1]	No. rows	No. stems per foot of row	Height before tests: Average stem (inches)	Height before tests: Average tallest stem[2] (inches)	Height after tests: Average stem (inches)	Height after tests: Average tallest stem[2] (inches)
A	32	76	24	27	28	35
B	31	66	26	31	31	40
C	31	63	27	33	34	40
Average for channel	31	68	26	30	31	38

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest stem was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest stem."

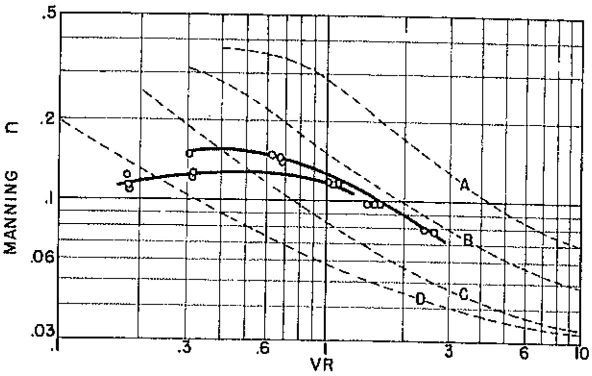

FIGURE 14.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 30, experiment 3.

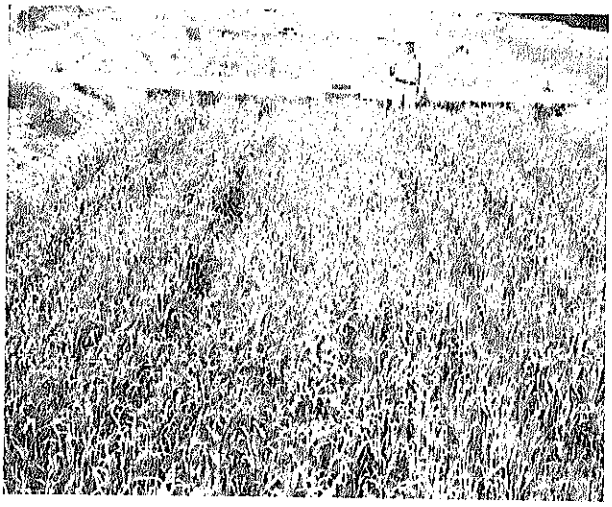

FIGURE 15.—Wheat in reach B of channel FC 29 before tests, experiment 5.

Twenty-six tests were run, but not all of them in the order of increasing magnitude (table 11). After the first eight tests (ranging from 4.7 to 15.0 ft^3/s) had been run, it was decided that the flow increments were too large, so five additional tests were run at discharges ranging from 2.9 to 7.5 ft^3/s. After the four tests at 34.6 ft^3/s were completed, additional or "repeat" tests at 10.8 and 5.2 ft^3/s were run. These tests served to determine if any changes attributable to growth had taken place in the flow-retarding properties of the vegetation over the 10 days of the experiment. Generally, three sill heights were used, except for the use of two heights for the two lowest flows. For the highest flow four sill heights were used.

FIGURE 16.—Wheat across center of reach C of channel FC 29, experiment 5. (Plants in foreground were cut to show height and density of stand.)

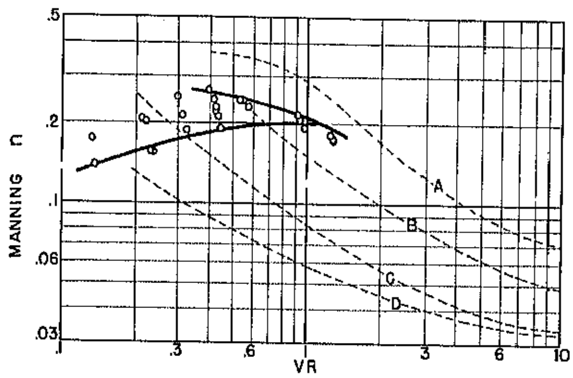

FIGURE 17.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 29, experiment 5.

The Manning n values for the tests are plotted against the corresponding values of VR in figure 17. The n values for the flows of approximately 5 and 10 ft^3/s for the repeat tests were smaller than those for the initial tests (table 12). Since 7 days had elapsed between the two sets of tests and some plant growth had occurred, these differences were unexpected. It was thought that the growth of the vegetation would have increased the friction factor. The decrease is attributed to the drying of the lower leaves and to the cleaning or combing effect on the vegetation by intervening, larger flows. Any change in the n–VR relationship attributable to vegetative growth

(Continued on page 21.)

TABLE 11. — *Hydraulic elements and friction factors for experiment 5, wheat in channel FC 29*

[*Q*, Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	*Q*	*A*	*V*	*P*	*R*	*S*	°F	*C*	*n*	n_k	*VR*	%
Test 1:												
Reach A	4.74	19.9	0.24	23.5	0.848	0.00200	72	5.78	0.252	0.176	0.202	0
B	4.74	16.7	.28	22.5	.741	.00235	72	6.81	.209	.144	.210	0
C	4.74	12.9	.37	22.0	.585	.00255	72	9.50	.143	.098	.215	0
Average	...	...	...	...	.725	......	...	7.36	.201	.139	.209	...
Test 2:												
Reach A	4.75	20.2	0.24	23.5	0.860	0.00198	72	5.69	0.256	0.180	0.202	0
B	4.75	17.5	.27	22.6	.774	.00220	72	6.59	.216	.150	.211	0
C	4.75	14.1	.34	22.4	.632	.00206	72	9.31	.147	.102	.212	0
Average	...	...	...	...	.755	......	...	7.20	.206	.144	.208	...
Test 3:												
Reach A	10.3	32.4	0.32	25.1	1.29	0.00225	72	5.92	0.264	0.205	0.412	0
B	10.3	27.7	.37	24.3	1.14	.00286	72	6.52	.236	.178	.424	0
C	10.3	20.5	.50	23.5	.874	.00380	72	8.71	.168	.123	.439	0
Average	...	...	...	...	1.10	......	...	7.05	.223	.169	.425	...
Test 4:												
Reach A	10.4	33.2	0.31	25.3	1.31	0.00209	72	5.96	0.263	0.205	0.409	15
B	10.4	29.7	.35	24.6	1.21	.00244	72	6.40	.242	.185	.421	5
C	10.4	24.7	.42	24.1	1.03	.00260	72	8.09	.185	.140	.432	0
Average	...	...	...	...	1.18	......	...	6.82	.230	.177	.421	...
Test 5:												
Reach A	10.3	39.3	0.26	25.9	1.51	0.00135	73	5.82	0.275	0.222	0.397	20
B	10.3	38.9	.27	25.9	1.50	.00140	73	5.81	.276	.222	.399	5
C	10.3	38.6	.27	26.1	1.48	.00106	73	6.76	.236	.191	.397	2
Average	...	...	...	...	1.50	......	...	6.13	.262	.212	.398	...
Test 6:												
Reach A	15.0	41.6	0.36	26.7	1.56	0.00195	73	6.56	0.246	0.201	0.565	45
B	15.0	38.8	.39	26.0	1.49	.00212	73	6.88	.233	.189	.577	10
C	15.0	34.7	.43	25.7	1.35	.00233	73	7.74	.204	.162	.586	1
Average	...	...	...	...	1.47	......	...	7.06	.228	.184	.576	...
Test 7:												
Reach A	15.1	48.9	0.31	27.7	1.76	0.00121	73	6.67	0.246	0.208	0.542	80
B	15.1	49.0	.31	27.4	1.79	.00119	73	6.67	.248	.210	.551	35
C	15.1	48.8	.31	27.6	1.77	.00117	73	6.76	.243	.206	.545	10
Average	...	...	...	...	1.77	......	...	6.70	.246	.208	.546	...
Test 8:												
Reach A	15.1	52.9	0.28	28.2	1.87	0.000900	73	6.94	0.239	0.205	0.533	90
B	15.1	54.2	.28	28.2	1.92	.000860	73	6.86	.243	.210	.536	70
C	15.1	55.6	.27	28.3	1.97	.000853	73	6.64	.252	.219	.536	20
Average	...	...	...	...	1.92	......	...	6.81	.245	.211	.535	...
Test 9:												
Reach A	2.91	12.3	0.24	22.1	0.556	0.00175	73	7.60	0.177	0.116	0.132	0
B	2.91	10.3	.28	21.4	.482	.00200	73	9.08	.145	.094	.136	0
C	2.91	8.07	.36	20.9	.386	.00194	73	13.2	.096	.064	.139	0
Average	...	...	...	...	.475	......	...	9.96	.139	.091	.136	...

TABLE 11. — *Hydraulic elements and friction factors for experiment 5, wheat in channel FC 29* — Continued

[*Q*, Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 10:												
Reach A	2.91	13.6	0.21	22.2	0.615	0.00148	73	7.06	0.194	0.129	0.131	0
B	2.91	13.6	.21	22.2	.615	.00121	73	7.81	.176	.118	.131	0
C	2.91	14.3	.20	22.5	.635	.000706	73	9.62	.143	.099	.130	0
Average	...	...	...	...	.622	......	...	8.16	.171	.115	.131	...
Test 11:												
Reach A	7.43	24.1	0.31	23.8	1.01	0.00215	73	6.61	0.226	0.167	0.311	0
B	7.43	20.4	.36	23.1	.884	.00256	73	7.63	.192	.139	.321	0
C	7.43	15.8	.47	22.5	.704	.00297	73	10.3	.138	.097	.330	0
Average	...	...	...	...	.866	......	...	8.18	.185	.134	.321	...
Test 12:												
Reach A	7.46	26.7	0.28	24.5	1.09	0.00189	74	6.14	0.246	0.185	0.304	1
B	7.46	24.3	.31	24.0	1.01	.00197	74	6.88	.217	.161	.310	1
C	7.46	22.0	.34	23.7	.926	.00176	74	8.41	.175	.129	.315	0
Average	...	...	...	...	1.01	......	...	7.14	.213	.158	.310	...
Test 13:												
Reach A	7.46	31.9	0.23	25.0	1.28	0.00131	74	5.71	0.273	0.211	0.300	5
B	7.46	31.9	.23	24.9	1.28	.00110	74	6.24	.250	.194	.300	1
C	7.46	33.0	.22	25.4	1.30	.000853	74	6.76	.231	.181	.293	0
Average	...	...	...	...	1.29	......	...	6.24	.251	.195	.298	...
Test 14:												
Reach A	25.3	54.2	0.47	28.4	1.91	0.00175	73	8.07	0.206	0.179	0.892	95
B	25.3	51.5	.49	27.6	1.86	.00220	73	7.68	.217	.186	.913	75
C	25.3	46.2	.55	27.1	1.71	.00282	73	7.87	.209	.176	.935	15
Average	...	...	...	...	1.83	......	...	7.87	.211	.180	.913	...
Test 15:												
Reach A	25.4	50.9	0.50	28.0	1.82	0.00215	73	7.99	0.207	0.178	0.910	95
B	25.4	46.3	.55	27.1	1.71	.00285	73	7.86	.208	.176	.939	55
C	25.4	37.5	.68	26.0	1.41	.00419	73	8.73	.184	.149	.976	5
Average	...	...	...	...	1.66	......	...	8.19	.200	.168	.942	...
Test 16:												
Reach A	25.5	49.6	0.52	27.8	1.78	0.00229	72	8.06	0.204	0.174	0.917	90
B	25.5	43.3	.59	26.8	1.61	.00317	72	8.26	.196	.164	.950	15
C	25.5	33.0	.77	25.4	1.30	.00553	72	9.13	.172	.137	1.01	5
Average	...	...	...	...	1.56	......	...	8.48	.191	.158	.959	...
Test 17:												
Reach A	34.5	58.1	0.59	29.2	1.99	0.00207	72	9.25	0.181	0.160	1.18	98
B	34.5	53.0	.65	28.3	1.87	.00297	72	8.73	.191	.165	1.22	85
C	34.5	42.6	.81	26.8	1.59	.00493	72	9.14	.178	.148	1.29	30
Average	...	...	...	...	1.82	......	...	9.04	.183	.158	1.23	...
Test 18:												
Reach A	34.6	57.0	0.61	28.9	1.97	0.00217	72	9.28	0.181	0.159	1.20	98
B	34.6	51.5	.67	27.9	1.85	.00313	72	8.82	.187	.163	1.24	85
C	34.6	40.2	.86	26.4	1.52	.00541	72	9.49	.170	.140	1.31	25
Average	...	...	...	...	1.78	......	...	9.19	.179	.154	1.25	...

TABLE 11. — *Hydraulic elements and friction factors for experiment 5, wheat in channel FC 29* — Continued

[Q, Discharge, ft^3/s. A, Area, ft^2. V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 19:												
Reach A	34.6	56.6	0.61	28.9	1.96	0.00219	72	9.34	0.179	0.157	1.20	98
B	34.6	50.9	.68	27.8	1.83	.00325	72	8.82	.188	.162	1.24	80
C	34.6	38.6	.90	26.1	1.48	.00596	72	9.53	.168	.138	1.33	25
Average	...	...	...	...	1.76	......	...	9.23	.178	.152	1.26	...
Test 20:												
Reach A	34.6	56.4	0.61	28.8	1.96	0.00223	72	9.28	0.181	0.158	1.20	98
B	34.6	50.7	.68	27.6	1.83	.00328	72	8.81	.188	.162	1.25	75
C	34.6	38.2	.91	26.1	1.47	.00608	72	9.58	.168	.137	1.33	20
Average	...	...	...	...	1.75	......	...	9.22	.179	.152	1.26	...
Test 21:												
Reach A	10.7	29.8	0.36	24.7	1.21	0.00225	72	6.87	0.225	0.173	0.434	0
B	10.7	25.7	.42	24.0	1.07	.00258	72	7.91	.191	.145	.445	0
C	10.7	20.4	.52	23.4	.873	.00318	72	9.95	.146	.109	.457	0
Average	...	...	...	...	1.05	......	...	8.24	.187	.142	.445	...
Test 22:												
Reach A	10.8	32.9	0.33	25.2	1.31	0.00192	73	6.56	0.239	0.187	0.431	0
B	10.8	30.4	.36	24.8	1.23	.00196	73	7.23	.214	.166	.437	0
C	10.8	28.4	.38	24.8	1.15	.00181	73	8.35	.184	.142	.438	0
Average	...	...	...	...	1.23	......	...	7.38	.212	.165	.435	...
Test 23:												
Reach A	10.8	39.1	0.28	26.0	1.50	0.00133	73	6.20	0.258	0.209	0.416	0
B	10.8	39.0	.28	26.0	1.50	.00125	73	6.39	.251	.203	.416	0
C	10.8	39.5	.27	26.3	1.50	.00103	73	6.97	.230	.187	.411	0
Average	...	...	...	...	1.50	......	...	6.52	.246	.200	.414	...
Test 24:												
Reach A	5.20	18.0	0.29	23.1	0.783	0.00194	72	7.39	0.194	0.136	0.226	0
B	5.20	15.2	.34	22.2	.683	.00219	72	8.86	.158	.110	.234	0
C	5.20	11.8	.44	21.8	.542	.00257	72	11.8	.114	.079	.238	0
Average	...	...	...	...	.669	......	...	9.35	.155	.108	.233	...
Test 25:												
Reach A	5.20	18.2	0.28	23.1	0.790	0.00190	72	7.36	0.195	0.137	0.225	0
B	5.20	15.8	.33	22.5	.703	.00201	72	8.75	.161	.112	.231	0
C	5.20	13.6	.38	22.1	.616	.00190	72	11.1	.124	.087	.235	0
Average	...	...	...	...	.703	......	...	9.07	.160	.112	.230	...
Test 26:												
Reach A	5.21	21.8	0.24	23.7	0.918	0.00136	75	6.79	0.216	0.157	0.220	0
B	5.21	21.9	.24	23.7	.923	.00115	75	7.30	.202	.147	.220	0
C	5.21	22.8	.23	24.0	.951	.000787	75	8.33	.178	.131	.217	0
Average	...	...	...	...	.931	......	...	7.47	.199	.145	.219	...

is probably small because of the relatively short duration of the experiment.

Wheat in channel FC 30

The wheat was drilled in 7-inch rows running crosswise in the channel. When the tests were begun, the wheat was just starting to head out. At this time it had an average height of 26 inches. During the 10-day period of the tests it grew an additional 8 inches to reach an average height of 34 inches. Table 13 gives the stand counts and stem heights before and after the tests. Figure 18 shows reach B before the tests, and figure 19 shows a typical cross section in the center of reach B after the tests.

Twenty tests were run during this experiment, with discharge rates ranging from 3.9 to 99.0 ft^3/s. Three sill heights were installed for most of the discharge rates. The hydraulic elements and friction factors for the experiment are given in table 14. The Manning n values for the tests are plotted against the corresponding values of VR in figure 20.

(Continued on page 24.)

TABLE 12.—*Discharge rates and Manning* n *values for initial and repeat tests in channel FC 29, experiment 5*

Test No.	Discharge rate (ft^3/s)	Manning n
	Initial tests	
2	4.75	0.206
4	10.4	.230
	Repeat tests	
25	5.20	0.160
22	10.8	.212

TABLE 13.—*Stand counts and stem heights for wheat before and after tests in channel FC 30, experiment 5*

Reach[1]	No. stems per foot of row	Height before tests		Height after tests	
		Average stem (inches)	Average tallest stem[2] (inches)	Average stem (inches)	Average tallest stem[2] (inches)
A	89	24	33	33	41
B	80	26	36	34	42
C	65	28	40	34	42
Average for channel	79	26	36	34	42

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest stem was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest stem."

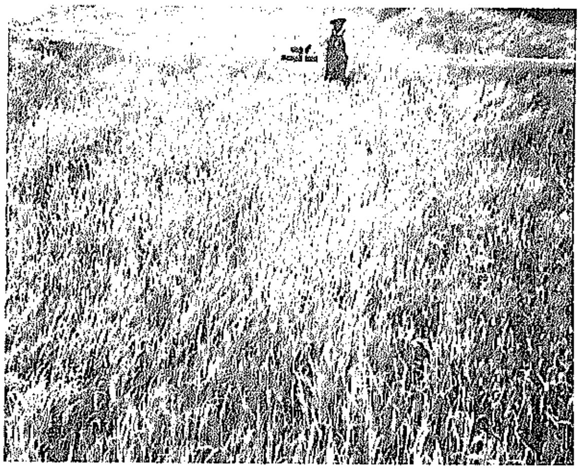

FIGURE 18.—Wheat in reach B of channel FC 30 before tests, experiment 5.

FIGURE 19.—Wheat across center of reach B of channel FC 30, experiment 5. (Rows are transverse in channel.)

TABLE 14. — *Hydraulic elements and friction factors for experiment 5, wheat in channel FC 30*

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	3.94	27.8	0.14	25.2	1.10	0.00183	74	3.16	0.480	0.348	0.156	0
B	3.94	24.5	.16	24.8	.989	.00231	74	3.37	.443	.319	.159	0
C	3.94	17.5	.22	23.9	.733	.00339	74	4.51	.315	.208	.165	0
Average	. . .	. . .	. . .	. . .	.941	. . . . . .	. . .	3.68	.413	.292	.160	. . .
Test 2:												
Reach A	3.93	27.6	0.14	25.1	1.10	0.00185	75	3.15	0.484	0.349	0.156	0
B	3.93	24.4	.16	24.6	.992	.00231	75	3.36	.445	.313	.160	0
C	3.93	17.6	.22	23.8	.738	.00327	75	4.56	.313	.207	.165	0
Average	. . .	. . .	. . .	. . .	.943	. . . . . .	. . .	3.69	.414	.290	.160	. . .
Test 3:												
Reach A	3.97	28.1	0.14	25.3	1.11	0.00183	76	3.13	0.486	0.352	0.157	0
B	3.97	25.3	.16	24.7	1.02	.00217	76	3.34	.450	.319	.160	0
C	3.97	19.6	.20	24.2	.812	.00247	76	4.51	.320	.218	.164	0
Average	. . .	. . .	. . .	. . .	.981	. . . . . .	. . .	3.66	.419	.296	.160	. . .
Test 4:												
Reach A	3.95	30.6	0.13	25.6	1.19	0.00139	77	3.17	0.485	0.359	0.154	0
B	3.95	29.9	.13	25.5	1.18	.00141	77	3.24	.478	.350	.156	0
C	3.95	28.1	.14	25.2	1.12	.00107	77	4.08	.378	.274	.157	0
Average	. . .	. . .	. . .	. . .	1.16	. . . . . .	. . .	3.50	.447	.328	.156	. . .
Test 5:												
Reach A	2.07	19.1	0.11	24.0	0.797	0.00151	75	3.11	0.461	0.306	0.086	0
B	2.07	17.8	.12	23.7	.754	.00153	75	3.41	.417	.273	.088	0
C	2.07	15.3	.14	23.6	.651	.00156	75	4.23	.329	.210	.088	0
Average	. . .	. . .	. . .	. . .	.734	. . . . . .	. . .	3.58	.402	.263	.087	. . .
Test 6:												
Reach A	5.70	35.3	0.16	26.3	1.34	0.00176	75	3.34	0.472	0.360	0.217	0
B	5.70	32.2	.18	25.8	1.25	.00225	75	3.34	.465	.349	.221	0
C	5.70	26.3	.22	25.1	1.05	.00231	75	4.41	.342	.248	.228	0
Average	. . .	. . .	. . .	. . .	1.21	. . . . . .	. . .	3.70	.426	.319	.222	. . .
Test 7:												
Reach A	5.70	36.8	0.16	26.2	1.40	0.00145	75	3.44	0.460	0.357	0.217	0
B	5.70	36.3	.16	26.4	1.37	.00168	75	3.27	.481	.371	.215	0
C	5.70	33.4	.17	25.8	1.29	.00133	75	4.13	.378	.289	.221	0
Average	. . .	. . .	. . .	. . .	1.35	. . . . . .	. . .	3.61	.440	.339	.218	. . .
Test 8:												
Reach A	5.70	40.6	0.14	27.1	1.50	0.00115	75	3.39	0.473	0.373	0.212	0
B	5.70	40.4	.14	27.0	1.50	.00126	75	3.24	.494	.390	.212	0
C	5.70	39.4	.14	26.6	1.48	.000873	75	4.04	.395	.313	.215	0
Average	. . .	. . .	. . .	. . .	1.49	. . . . . .	. . .	3.56	.454	.359	.213	. . .
Test 9:												
Reach A	10.2	48.9	0.21	28.2	1.73	0.00134	72	4.34	0.377	0.313	0.362	15
B	10.2	47.4	.22	28.0	1.69	.00177	72	3.95	.413	.340	.365	5
C	10.2	44.0	.23	27.2	1.62	.00144	72	4.80	.338	.276	.376	3
Average	. . .	. . .	. . .	. . .	1.68	. . . . . .	. . .	4.36	.376	.310	.368	. . .

BLE 14. — *Hydraulic elements and friction factors for experiment 5, wheat in channel FC 30* — Continued

Discharge, ft^3/s. *A*, Area, ft^2. *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	*Q*	*A*	*V*	*P*	*R*	*S*	°F	*C*	*n*	n_k	*VR*	%
10:												
Reach A	10.2	52.3	0.20	28.6	1.83	0.00109	72	4.39	0.376	0.317	0.359	20
B	10.2	52.2	.20	28.4	1.84	.00138	72	3.89	.425	.358	.361	10
C	10.2	50.4	.20	27.8	1.81	.000993	73	4.79	.346	.290	.367	3
Average	...	...	...	...	1.83	......	...	4.36	.382	.322	.362	...
11:												
Reach A	10.2	56.7	0.18	29.2	1.94	0.000833	72	4.50	0.370	0.318	0.351	30
B	10.2	57.7	.18	29.3	1.97	.00101	72	3.97	.423	.362	.349	10
C	10.2	57.3	.18	28.6	2.00	.000700	72	4.78	.350	.304	.358	5
Average	...	...	...	...	1.97	......	...	4.42	.381	.328	.353	...
12:												
Reach A	18.3	55.4	0.33	29.1	1.90	0.00183	74	5.61	0.297	0.254	0.629	45
B	18.3	51.4	.36	28.4	1.81	.00247	74	5.33	.311	.262	.644	3
C	18.3	44.1	.42	27.2	1.68	.00266	74	6.34	.256	.211	.674	.0
Average	...	...	...	...	1.78	......	...	5.76	.288	.242	.649	...
13:												
Reach A	18.4	62.1	0.30	30.0	2.07	0.00132	75	5.66	0.298	0.262	0.613	65
B	18.4	61.0	.30	29.6	2.06	.00162	75	5.21	.324	.283	.620	40
C	18.4	57.5	.32	28.6	2.01	.00136	75	6.10	.276	.240	.642	25
Average	...	...	...	...	2.05	......	...	5.66	.299	.262	.625	...
14:												
Reach A	18.4	71.6	0.26	31.2	2.30	0.000880	75	5.71	0.300	0.271	0.591	85
B	18.4	72.7	.25	31.4	2.32	.00100	75	5.25	.329	.296	.587	65
C	18.4	71.7	.26	30.8	2.33	.000707	75	6.30	.273	.248	.596	50
Average	...	...	...	...	2.32	......	...	5.75	.301	.272	.591	...
15:												
Reach A	34.0	66.1	0.51	30.6	2.16	0.00183	74	8.17	0.209	0.186	1.11	98
B	34.0	61.7	.55	29.8	2.07	.00254	74	7.58	.224	.197	1.14	90
C	34.0	53.6	.63	28.2	1.90	.00287	74	8.58	.194	.169	1.20	75
Average	...	...	...	...	2.04	......	...	8.11	.209	.184	1.15	...
16:												
Reach A	34.2	76.9	0.44	31.8	2.42	0.00117	73	8.36	0.208	0.191	1.08	100
B	34.2	76.3	.45	31.9	2.39	.00147	73	7.57	.230	.209	1.07	98
C	34.2	72.9	.47	30.8	2.37	.00134	73	8.34	.207	.190	1.11	90
Average	...	...	...	...	2.39	......	...	8.09	.215	.197	1.09	...
17:												
Reach A	34.1	85.2	0.40	33.1	2.57	0.000827	73	8.68	0.202	0.188	1.03	100
B	34.1	87.1	.39	33.6	2.59	.000907	73	8.06	.217	.203	1.01	100
C	34.1	85.7	.40	32.6	2.63	.000787	73	8.74	.201	.189	1.05	100
Average	...	...	...	...	2.60	......	...	8.49	.207	.193	1.03	...
18:												
Reach A	60.0	81.4	0.74	32.8	2.48	0.00145	74	12.3	0.142	0.132	1.83	100
B	60.0	79.5	.75	32.5	2.45	.00177	74	11.4	.152	.142	1.85	100
C	60.0	74.2	.81	31.0	2.39	.00175	74	12.5	.139	.128	1.94	100
Average	...	...	...	...	2.44	......	...	12.1	.144	.134	1.87	...

TABLE 14. — *Hydraulic elements and friction factors for experiment 5, wheat in channel FC 30* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 19:												
Reach A	60.0	90.9	0.66	33.9	2.68	0.00107	74	12.3	0.143	0.136	1.77	100
B	60.0	91.5	.66	34.4	2.66	.00126	74	11.3	.156	.148	1.74	100
C	60.0	88.0	.68	32.9	2.68	.00116	74	12.2	.144	.137	1.82	100
Average	...	...	...	...	2.67	......	...	11.9	.148	.140	1.78	...
Test 20:												
Reach A	99.0	84.9	1.17	33.0	2.57	0.00177	74	17.3	0.101	0.096	3.00	100
B	99.0	81.0	1.22	32.7	2.48	.00220	74	16.5	.105	.099	3.03	100
C	99.0	73.2	1.35	30.8	2.38	.00243	74	17.8	.097	.091	3.22	100
Average	...	...	...	...	2.48	......	...	17.2	.101	.095	3.08	...

Experiment 7

Wheat in channel FC 29

The wheat was drilled in 14-inch rows running lengthwise in the channel. When the tests were begun, the wheat was green and just starting to head out. Its average height was 27 inches before the tests and 30 inches after the tests. Table 15 gives the stand counts and stem heights before and after the tests. Figure 21 shows reach B before the tests, and figure 22 is a cross section of the channel showing the wheat after the tests.

Twelve tests were run during this experiment, with discharge rates ranging from 2.5 to 37.2 ft³/s. Three sill heights were used for each flow, except the first flow when two sill heights were used and the last flow when no sill was used. The hydraulic data and friction factors for the experiment are given in table 16. The Manning n values for the tests are plotted against the corresponding values of VR in figure 23.

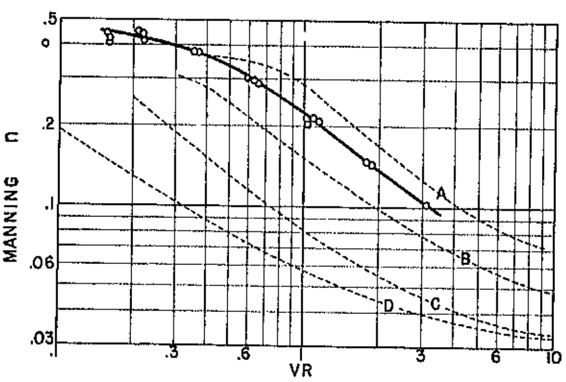

FIGURE 20.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 30, experiment 5.

Wheat in channel FC 30

The wheat was drilled in 7-inch rows running lengthwise in the channel. When the tests were begun, the wheat was just starting to head out. During the tests the vegetation reached its maximum bulk. Table 17 gives the stand counts and stem lengths before and after the tests. Figure 24 shows reach B before the tests. Most of the wheat was down after the tests, as shown in the cross section of reach B in figure 25.

FIGURE 21.—Wheat in reach B of channel FC 29 before tests, experiment 7.

TABLE 15.—*Stand counts and stem heights for wheat before and after tests in channel FC 29, experiment 7*

Reach[1]	No. rows	No. stems per foot of row	Height before tests		Height after tests	
			Average stem (inches)	Average tallest stem[2] (inches)	Average stem (inches)	Average tallest stem[2] (inches)
A	17	81	28	36	32	44
B	17	67	25	32	30	43
C	17	70	27	32	29	42
Average for channel	17	73	27	33	30	43

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest stem was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest stem."

FIGURE 22.—Wheat across center of reach B of channel FC 29, experiment 7. (Plants in foreground were cut to show height and density of stand.)

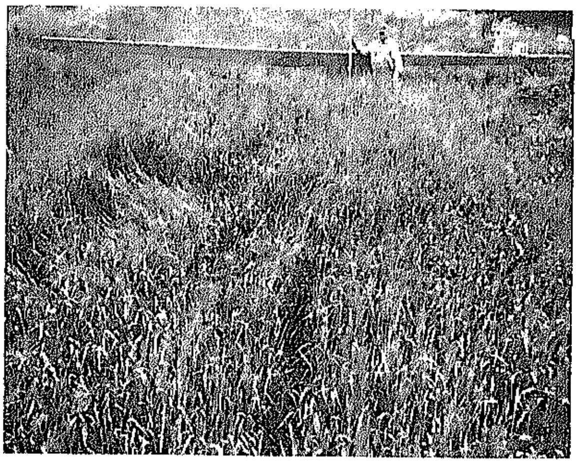

FIGURE 24.—Wheat in reach B of channel FC 30 before tests, experiment 7.

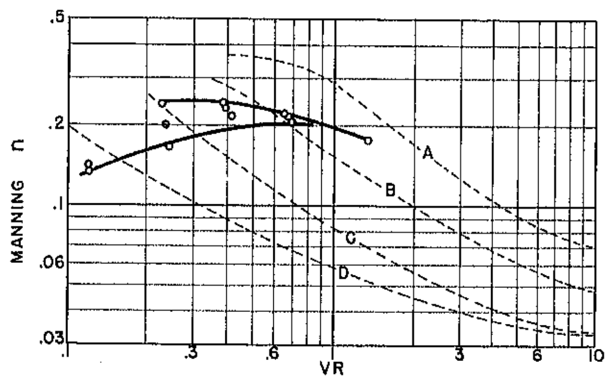

FIGURE 23.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 29, experiment 7.

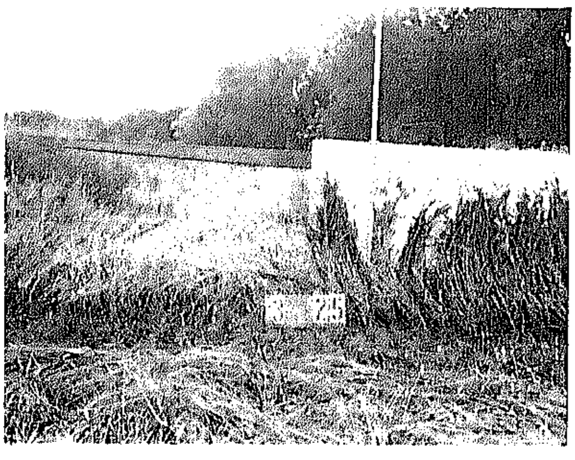

FIGURE 25.—Wheat across center of reach B of channel FC 30 after tests, experiment 7.

TABLE 16.—*Hydraulic elements and friction factors for experiment 7, wheat in channel FC 29*

[Q, Discharge, ft^3/s. A, Area, ft^2. V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	2.53	10.2	0.25	21.6	0.475	0.00135	66	9.74	0.135	0.088	0.117	0
B	2.53	9.64	.26	21.1	.457	.00165	66	9.53	.137	.089	.120	0
C	2.53	8.39	.30	20.7	.406	.00203	66	10.5	.123	.078	.122	0
Average	...	...	...	...	.446	......	...	9.92	.132	.085	.120	...
Test 2:												
Reach A	2.54	10.7	0.24	21.6	0.493	0.00126	67	9.54	0.138	0.091	0.117	0
B	2.54	10.6	.24	21.2	.500	.00139	67	9.06	.146	.096	.120	0
C	2.54	10.8	.24	21.2	.508	.00116	67	9.67	.137	.091	.119	0
Average	...	...	...	...	.500	......	...	9.42	.140	.093	.119	...
Test 3:												
Reach A	5.38	18.2	0.30	22.8	0.796	0.00157	68	8.37	0.172	0.122	0.236	0
B	5.38	16.4	.33	22.2	.736	.00203	68	8.48	.167	.117	.241	0
C	5.38	13.5	.40	21.8	.618	.00282	68	9.56	.144	.099	.247	0
Average	...	...	...	...	.717	......	...	8.80	.161	.113	.241	...
Test 4:												
Reach A	5.53	22.5	0.25	23.6	0.950	0.00113	65	7.51	0.197	0.145	0.234	0
B	5.53	22.6	.24	23.4	.966	.00121	65	7.16	.207	.152	.237	0
C	5.53	22.6	.24	23.6	.957	.00105	65	7.69	.192	.142	.234	0
Average	...	...	...	...	.958	......	...	7.45	.199	0.146	.235	...
Test 5:												
Reach A	5.60	28.1	0.20	24.4	1.15	0.000720	66	6.91	0.222	0.168	0.229	0
B	5.60	30.0	.19	24.5	1.23	.000727	66	6.25	.248	.190	.230	0
C	5.60	32.9	.17	25.0	1.31	.000533	66	6.43	.244	.190	.223	0
Average	...	...	...	...	1.23	......	...	6.53	.238	.183	.227	...
Test 6:												
Reach A	10.1	31.8	0.32	24.9	1.27	0.00155	66	7.16	0.217	0.170	0.404	0
B	10.1	29.9	.34	24.5	1.22	.00186	66	7.09	.218	.169	.412	0
C	10.1	28.0	.36	24.3	1.15	.00194	66	7.62	.201	.154	.414	0
Average	...	...	...	...	1.21	......	...	7.29	.212	.164	.410	...
Test 7:												
Reach A	10.1	36.0	0.28	25.6	1.41	0.00120	66	6.83	0.231	0.185	0.396	0
B	10.1	35.8	.28	25.3	1.41	.00127	66	6.66	.237	.190	.398	0
C	10.1	36.4	.28	25.6	1.42	.00108	66	7.07	.224	.180	.393	0
Average	...	...	...	...	1.41	......	...	6.85	.231	.185	.396	...
Test 8:												
Reach A	10.2	41.6	0.24	26.1	1.59	0.000720	69	7.24	0.226	0.184	0.390	0
B	10.2	43.4	.23	26.3	1.65	.000833	69	6.31	.257	.213	.386	0
C	10.2	45.9	.22	27.0	1.70	.000633	69	6.76	.242	.202	.377	0
Average	...	...	...	...	1.65	......	...	6.77	.242	.200	.384	...
Test 9:												
Reach A	18.3	45.0	0.41	27.0	1.67	0.00173	66	7.57	0.215	0.180	0.680	0
B	18.3	42.0	.44	26.6	1.58	.00214	66	7.49	.216	.178	.689	0
C	18.3	38.8	.47	26.2	1.48	.00233	66	8.01	.200	.163	.697	0
Average	...	...	...	...	1.58	......	...	7.69	.210	.174	.689	...

TABLE 16. — *Hydraulic elements and friction factors for experiment 7, wheat in channel FC 29* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 10:												
Reach A	18.3	49.0	0.37	27.8	1.76	0.00136	67	7.64	0.215	0.183	0.658	0
B	18.3	48.2	.38	27.3	1.76	.00159	67	7.20	.228	.193	.671	2
C	18.3	47.5	.39	27.4	1.73	.00134	67	8.01	.205	.173	.668	0
Average	...	...	...	...	1.75	......	...	7.62	.216	.183	.666	...
Test 11:												
Reach A	18.4	53.1	0.35	28.3	1.88	0.00111	68	7.57	0.220	0.189	0.650	20
B	18.4	53.4	.34	28.3	1.89	.00117	68	7.31	.228	.196	.650	20
C	18.4	54.4	.34	28.5	1.91	.000973	68	7.84	.213	.184	.646	20
Average	...	...	...	...	1.89	......	...	7.57	.220	.190	.649	...
Test 12:												
Reach A	37.2	58.5	0.64	29.0	2.02	0.00229	66	9.36	0.181	0.159	1.28	60
B	37.2	52.9	.70	28.0	1.89	.00289	66	9.52	.175	.152	1.33	50
C	37.2	44.0	.85	27.0	1.63	.00407	66	10.4	.157	.132	1.38	50
Average	...	...	...	...	1.85	......	...	9.76	.171	.148	1.33	...

TABLE 17.—*Stand counts and stem heights for wheat before and after tests in channel FC 30, experiment 7*

Reach[1]	No. rows	No. stems per foot of row	Height before tests: Average stem (inches)	Height before tests: Average tallest stem[2] (inches)	Height after tests: Average stem (inches)	Height after tests: Average tallest stem[2] (inches)
A	33	52	33	39	39	44
B	33	54	35	43	39	44
C	34	51	34	43	40	44
Average for channel	33	52	34	42	39	44

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest stem was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest stem."

Nineteen tests, ranging in discharge from 3.2 to 58.8 ft³/s, were run. Three sill heights were set for each flow rate, except for the smaller and larger flows. The hydraulic elements and friction factors for the experiment are given in table 18. The Manning n values for the tests are plotted against the corresponding values of VR in figure 26.

Experiment 2

Sorghum in channel FC 29

'Redlan Kafir' sorghum was drilled in 40-inch rows. When the tests were begun, the plants were in full seed head, but the leaves were still green. The flow-retarding properties of this

(Continued on page 30.)

TABLE 18.—*Hydraulic elements and friction factors for experiment 7, wheat in channel FC 30*

[Q, Discharge, ft^3/s. A, Area, ft^2. V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	3.15	17.4	0.18	23.6	0.738	0.00143	66	5.57	0.254	0.172	0.134	0
B	3.15	17.4	.18	23.2	.748	.00156	66	5.30	.267	.181	.135	0
C	3.15	12.4	.25	22.3	.556	.00267	66	6.60	.205	.132	.141	0
Average	...	...	...	...	.681	......	...	5.82	.242	.162	.137	...
Test 2:												
Reach A	3.16	18.0	0.18	23.7	0.760	0.00133	67	5.50	0.258	0.176	0.133	0
B	3.16	18.4	.17	23.5	.785	.00155	67	4.92	.292	.198	.135	0
C	3.16	14.1	.22	22.7	.621	.00210	67	6.23	.221	.145	.140	0
Average	...	...	...	...	.722	......	...	5.55	.257	.173	.136	...
Test 3:												
Reach A	1.86	12.4	0.15	22.6	0.550	0.00128	74	5.62	0.240	0.151	0.082	0
B	1.86	12.8	.14	22.2	.577	.00135	74	5.19	.262	.166	.084	0
C	1.86	9.28	.20	21.7	.427	.00206	74	6.74	.192	.117	.085	0
Average	...	...	...	...	.518	......	...	5.85	.231	.145	.084	...
Test 4:												
Reach A	1.85	13.5	0.14	23.0	0.588	0.00102	71	5.59	0.244	0.156	0.081	0
B	1.85	15.1	.12	22.7	.665	.000953	71	4.85	.288	.186	.081	0
C	1.85	13.8	.13	22.7	.611	.00107	71	5.24	.261	.168	.082	0
Average	...	...	...	...	.621	......	...	5.23	.264	.170	.081	...
Test 5:												
Reach A	1.58	18.2	0.09	23.9	0.761	0.000587	75	4.09	0.349	0.231	0.066	0
B	1.58	22.1	.07	24.1	.917	.000133	75	6.45	.225	.160	.065	0
C	1.58	23.4	.07	24.8	.944	.000253	75	4.35	.339	.237	.063	0
Average	...	...	...	...	.874	......	...	4.96	.304	.209	.065	...
Test 6:												
Reach A	2.55	19.8	0.13	24.0	0.825	0.000860	75	4.84	0.297	0.204	0.108	0
B	2.55	22.1	.12	24.0	.919	.000833	75	4.19	.350	.245	.107	0
C	2.55	21.5	.12	24.5	.881	.000727	75	4.70	.312	.216	.105	0
Average	...	...	...	...	.875	......	...	4.58	.320	.222	.107	...
Test 7:												
Reach A	2.95	27.7	0.11	25.0	1.11	0.000440	73	5.10	0.314	0.220	0.119	0
B	2.95	31.4	.09	25.5	1.23	.000433	73	4.06	.373	.286	.116	0
C	2.95	32.4	.09	25.9	1.25	.000380	73	4.18	.370	.280	.114	0
Average	...	...	...	...	1.20	......	...	4.45	.352	.262	.116	...
Test 8:												
Reach A	5.34	29.8	0.18	25.5	1.17	0.00115	69	4.91	0.313	0.234	0.211	0
B	5.34	30.6	.18	25.6	1.19	.00131	69	4.43	.347	.260	.208	0
C	5.34	28.1	.19	25.3	1.11	.00134	69	4.93	.310	.228	.211	0
Average	...	...	...	...	1.16	......	...	4.76	.323	.241	.210	...
Test 9:												
Reach A	5.45	37.2	0.15	26.6	1.40	0.000867	70	4.18	0.378	0.295	0.204	0
B	5.45	39.1	.14	26.6	1.47	.000867	70	3.90	.410	.323	.204	0
C	5.45	38.3	.14	26.4	1.45	.000867	70	4.01	.399	.312	.206	0
Average	...	...	...	...	1.44	......	...	4.03	.396	.310	.205	...

TABLE 18. — *Hydraulic elements and friction factors for experiment 7, wheat in channel FC 30* — Continued

[*Q*, Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	*Q*	*A*	*V*	*P*	*R*	*S*	°F	*C*	*n*	n_k	*VR*	%
Test 10:												
Reach A	5.53	45.8	0.12	27.8	1.65	0.000553	71	4.00	0.405	0.331	0.200	0
B	5.53	49.0	.11	28.0	1.75	.000547	71	3.65	.448	.372	.198	0
C	5.53	49.6	.11	27.8	1.78	.000460	71	3.91	.422	.350	.199	0
Average	...	...	...	...	1.73	......	...	3.85	.425	.351	.199	...
Test 11:												
Reach A	10.2	48.8	0.21	28.0	1.74	0.00129	68	4.41	0.373	0.309	0.364	5
B	10.2	48.6	.21	28.0	1.73	.00152	68	4.09	.402	.332	.363	5
C	10.2	44.7	.23	27.3	1.64	.00167	68	4.36	.373	.304	.374	5
Average	...	...	...	...	1.70	......	...	4.29	.383	.315	.367	...
Test 12:												
Reach A	10.2	55.3	0.18	29.0	1.90	0.000947	68	4.34	0.384	0.326	0.350	10
B	10.2	56.7	.18	29.0	1.95	.00105	68	3.98	.421	.359	.351	10
C	10.2	55.0	.18	28.4	1.94	.000993	68	4.21	.397	.339	.359	10
Average	...	...	...	...	1.93	......	...	4.18	.401	.341	.353	...
Test 13:												
Reach A	10.2	63.9	0.16	30.2	2.11	0.000633	68	4.38	0.387	0.339	0.338	[1]15
B	10.2	66.7	.15	30.6	2.18	.000680	68	3.98	.428	.378	.334	[1]15
C	10.2	66.5	.15	30.0	2.21	.000607	68	4.18	.410	.362	.338	[1]15
Average	...	...	...	...	2.17	......	...	4.18	4.08	.360	.337	...
Test 14:												
Reach A	20.3	68.0	0.30	30.6	2.22	0.00129	68	5.58	0.306	0.273	0.664	80
B	20.3	67.8	.30	30.7	2.21	.00144	68	5.30	.322	.287	.661	60
C	20.3	63.9	.32	29.6	2.16	.00151	68	5.57	.307	.271	.687	50
Average	...	...	...	...	2.20	......	...	5.48	.312	.277	.671	...
Test 15:												
Reach A	20.3	76.0	0.27	31.8	2.39	0.000960	70	5.57	0.309	0.283	0.638	98
B	20.3	77.4	.26	32.3	2.40	.00103	70	5.26	.330	.300	.629	80
C	20.3	75.2	.27	31.2	2.41	.000993	70	5.51	.314	.287	.651	60
Average	...	...	...	...	2.40	......	...	5.45	.318	.290	.639	...
Test 16:												
Reach A	20.3	83.8	0.24	32.6	2.57	0.000640	69	5.96	0.294	0.273	0.622	100
B	20.3	87.2	.23	33.6	2.59	.000667	69	5.60	.312	.291	.603	95
C	20.3	86.3	.24	32.9	2.62	.000613	69	5.86	.300	.280	.616	95
Average	...	...	...	...	2.59	......	...	5.81	.302	.281	.614	...
Test 17:												
Reach A	34.3	76.0	0.45	31.5	2.42	0.00123	69	8.26	0.210	0.193	1.09	100
B	34.3	76.0	.45	32.0	2.37	.00136	69	7.94	.218	.199	1.07	100
C	34.3	72.3	.47	30.8	2.35	.00139	69	8.29	.209	.190	1.11	100
Average	...	...	...	...	2.38	......	...	8.16	.212	.194	1.09	...
Test 18:												
Reach A	34.4	83.8	0.41	32.9	2.55	0.000927	69	8.45	0.207	0.193	1.05	100
B	34.4	86.0	.40	33.4	2.57	.000947	69	8.11	.216	.202	1.03	100
C	34.4	83.8	.41	32.4	2.59	.000940	69	8.30	.212	.198	1.06	100
Average	...	...	...	...	2.57	......	...	8.29	.212	.198	1.05	...

See footnote at end of table.

TABLE 18. — *Hydraulic elements and friction factors for experiment 7, wheat in channel FC 30* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 19:												
Reach A	58.8	76.7	0.77	31.8	2.41	0.00167	68	12.1	0.143	0.133	1.85	100
B	58.8	74.4	.79	31.8	2.34	.00193	68	11.8	.147	.135	1.85	100
C	58.8	68.1	.86	30.3	2.25	.00218	68	12.3	.139	.127	1.94	100
Average	...	...	...	...	2.33	......	...	12.1	.143	.132	1.88	...

[1] Estimated.

stand were at a maximum. The stand was very good, with an average height of 43 inches. A few plants were as short as 16 inches, and others were as tall as 54 inches. Table 19 gives additional height data and stand counts. Figure 27 shows reach C during a flow of 38 ft³/s. Figure 28 shows a typical plant taken from the channel.

Nine flow tests, ranging in discharge rate from 6.6 to 38 ft³/s, were run. One sill height was used with each of the first seven flow rates, and two sill heights were used with the highest discharge rate, making nine tests in all. Velocities were measured with a Bentzel tube in a single vertical in the center of the channel during a test flow of 38 ft³/s. The hydraulic data and friction factors for the experiment

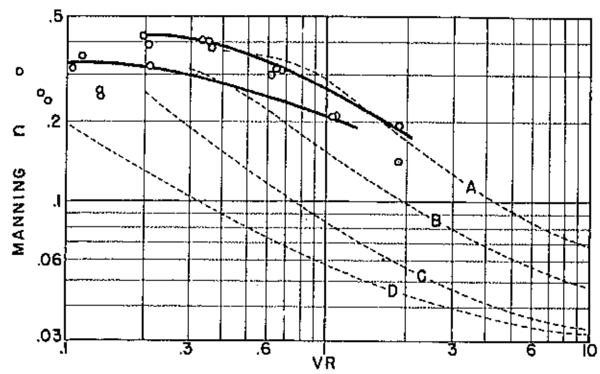

FIGURE 26.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 30, experiment 7.

TABLE 19.—*Stand counts and plant heights for 'Redlan Kafir' sorghum in channel FC 29, experiment 2*

Reach[1]	No. rows	No. stems per 10 feet of row	Height: Average leafy portion (inches)	Height: Average plant (inches)	Height: Average tallest plant[2] (inches)
A	7	20	30	42	47
B	7	22	32	43	50
C	7	26	30	44	54
Average for channel	7	23	31	43	50

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest plant was measured at 7 sampling points in each reach. The average of these measurements is the "average tallest plant."

FIGURE 27.—'Redlan Kafir' sorghum in reach C of channel FC 29 during flow of 38 ft³/s with depth of about 1.6 feet, experiment 2.

Table 20. — *Hydraulic elements and friction factors for experiment 2,* 'Redlan Kafir' *sorghum in channel FC 29*

[Q, Discharge, ft^3/s. A, Area, ft^2. V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	6.59	9.14	0.72	21.5	0.426	0.00106	85	33.9	0.038	0.030	0.307	0
B	6.59	10.4	.63	21.4	.487	.000907	85	30.1	.044	.035	.308	0
C	6.59	11.1	.59	21.5	.517	.000713	85	30.8	.043	.034	.306	0
Average	...	...	...	...	.477	......	...	31.6	.042	.033	.307	...
Test 2:												
Reach A	9.25	12.1	0.77	21.8	0.553	0.000993	85	32.8	0.041	0.034	0.424	0
B	9.25	12.9	.72	21.3	.606	.00109	85	27.8	.049	.039	.434	0
C	9.25	12.8	.72	21.8	.587	.00104	85	29.2	.047	.038	.423	0
Average	...	...	...	...	.582	......	...	29.9	.046	.037	.427	...
Test 3:												
Reach A	13.9	15.8	0.88	22.6	0.696	0.00112	83	31.6	0.044	0.037	0.614	0
B	13.9	16.4	.85	22.5	.729	.00125	83	28.1	.050	.041	.619	0
C	13.9	15.7	.88	22.4	.701	.00131	83	29.2	.048	.040	.620	0
Average	...	...	...	...	.709	......	...	29.6	.047	.039	.618	...
Test 4:												
Reach A	21.0	22.1	0.95	23.7	0.931	0.00146	83	25.8	0.057	0.048	0.886	0
B	21.0	21.6	.98	23.4	.924	.00159	83	25.4	.058	.048	.901	0
C	21.0	19.4	1.08	23.1	.840	.00178	83	27.9	.051	.043	.907	0
Average	...	...	...	...	.898	......	...	26.4	.055	.046	.898	...
Test 5:												
Reach A	22.5	26.8	0.84	24.4	1.10	0.00123	83	22.8	0.067	0.056	0.923	0
B	22.5	26.8	.84	24.1	1.11	.00139	83	21.3	.071	.060	.931	0
C	22.5	25.6	.88	24.1	1.07	.00140	83	22.7	.066	.058	.939	0
Average	...	...	...	...	1.09	......	...	22.3	.068	.058	.931	...
Test 6:												
Reach A	27.1	31.0	0.87	25.0	1.24	0.00144	83	20.6	0.075	0.064	1.08	0
B	27.1	30.1	.90	24.6	1.22	.00166	83	20.0	.077	.065	1.10	0
C	27.1	27.9	.97	24.3	1.15	.00169	83	22.0	.069	.059	1.12	0
Average	...	...	...	...	1.20	......	...	20.9	.074	.063	1.10	...
Test 7:												
Reach A	31.8	35.2	0.90	25.6	1.37	0.00163	83	19.1	0.082	0.071	1.24	0
B	31.8	33.4	.95	25.1	1.33	.00189	83	19.0	.082	.070	1.27	0
C	31.8	30.2	1.06	24.7	1.22	.00197	83	21.6	.071	.061	1.29	0
Average	...	...	...	...	1.31	......	...	19.9	.078	.067	1.27	...
Test 8:												
Reach A	38.0	44.7	0.85	26.7	1.68	0.00167	83	16.0	0.102	0.089	1.43	0
B	38.0	42.6	.89	26.5	1.61	.00187	83	16.3	.099	.086	1.44	0
C	38.0	39.4	.96	26.0	1.51	.00190	83	18.0	.089	.077	1.46	0
Average	...	...	...	...	1.60	......	...	16.8	.097	.084	1.44	...
Test 9:												
Reach A	38.0	49.9	0.76	27.6	1.81	0.00148	83	14.7	0.113	0.099	1.38	0
B	38.0	48.3	.79	27.2	1.77	.00167	83	14.5	.114	.100	1.39	0
C	38.0	46.2	.82	27.0	1.74	.00167	83	15.4	.106	.094	1.41	0
Average	...	...	...	...	1.77	......	...	14.9	.111	.098	1.39	...

are given in table 20. The Manning n values are plotted against the corresponding values of the hydraulic radius (R) in figure 29.

Sorghum in channel FC 30

'Hegari' sorghum was planted in 40-inch rows. When the tests were begun, it was tall and green and had probably acquired maximum flow-retarding properties. The plant height averaged 58 inches, with a minimum of 14 inches and a maximum of 80 inches. Table 21 gives additional height data and stand counts.

FIGURE 28.—Typical 'Redlan Kafir' sorghum plant from channel FC 29, experiment 2. (Rows run parallel to flow.)

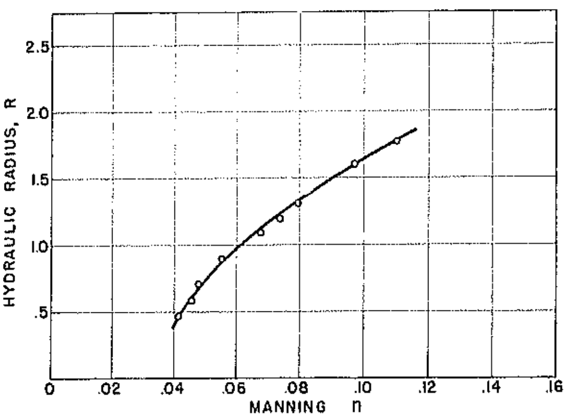

FIGURE 29.—Relation of Manning n to hydraulic radius (R) for flow tests on channel FC 29, experiment 2.

Figure 30 shows the channel during a flow of 38 ft^3/s. Figure 31 shows a typical plant cluster from the channel.

Nine flow tests, ranging in discharge rate from 7.0 to 60.7 ft^3/s, were run. One sill height was used with seven of the flows, and two sill heights were used with a flow of 21 ft^3/s, making nine tests in all. Table 22 gives the hydraulic elements and friction factors for the experiment. The Manning n values are plotted against the corresponding values of the hydraulic radius (R) in figure 32.

Experiment 4

Sorghum in channel FC 30

'Hegari' sorghum was planted in 20-inch rows. When the tests were begun, it was tall and

FIGURE 30.—'Hegari' sorghum in reach A of channel FC 30 during flow of 38 ft^3/s, experiment 2. (Crew is making measurements of water-surface elevation and water's edge location.)

TABLE 21.—*Stand counts and plant heights for 'Hegari' sorghum in channel FC 30, experiment 2*

Reach[1]	No. rows	No. stems per 10 feet of row	Average plant height (inches)	Average tallest plant[2] (inches)
A	7	41	52	62
B	7	44	61	76
C	7	40	60	76
Average for channel	7	42	58	71

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest plant was measured at 7 sampling points in each reach. The average of these measurements is the "average tallest plant."

TABLE 22. —*Hydraulic elements and friction factors for experiment 2,* 'Hegari' *sorghum in channel FC 30*

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	6.96	11.0	0.63	22.4	0.492	0.00109	80	27.2	0.049	0.038	0.310	0
B	6.96	11.4	.61	22.5	.509	.000973	80	27.3	.049	.038	.309	0
C	6.96	10.4	.67	22.2	.469	.000973	80	31.3	.042	.033	.313	0
Average	...	...	...	...	.490	......	...	28.6	.047	.036	.311	...
Test 2:												
Reach A	9.20	13.8	0.66	22.9	0.605	0.00105	80	26.3	0.052	0.041	0.402	0
B	9.20	14.2	.65	22.9	.620	.00105	80	25.4	.054	.043	.402	0
C	9.20	13.1	.70	22.7	.577	.000934	80	30.3	.045	.036	.406	0
Average	...	...	...	...	.601	......	...	27.3	.050	.040	.403	...
Test 3:												
Reach A	13.3	20.2	0.66	23.8	0.848	0.000900	82	24.0	0.060	0.049	0.561	0
B	13.3	21.1	.63	23.8	.883	.000873	82	22.8	.064	.052	.559	0
C	13.3	20.6	.65	23.8	.866	.000713	82	26.1	.056	.046	.561	0
Average	...	...	...	...	.866	......	...	24.3	.060	.049	.560	...
Test 4:												
Reach A	20.2	27.9	0.72	25.0	1.12	0.000993	81	21.6	0.070	0.059	0.809	0
B	20.2	28.6	.70	25.2	1.14	.000993	81	21.0	.073	.061	.804	0
C	20.2	27.6	.73	24.7	1.12	.000886	81	23.2	.066	.055	.818	0
Average	...	...	...	...	1.13	......	...	21.9	.070	.058	.810	...
Test 5:												
Reach A	27.0	35.7	0.76	26.0	1.37	0.00118	80	18.8	0.084	0.071	1.04	0
B	27.0	35.6	.76	26.0	1.37	.00117	80	18.9	.083	.071	1.04	0
C	27.0	33.6	.80	25.5	1.32	.00113	80	20.8	.075	.064	1.06	0
Average	...	...	...	...	1.35	......	...	19.5	.081	.069	1.05	...
Test 6:												
Reach A	37.2	49.8	0.74	28.0	1.78	0.00154	81	14.2	0.116	0.102	1.33	0
B	37.2	48.6	.76	27.7	1.75	.00141	81	15.4	.107	.094	1.34	0
C	37.2	45.3	.82	27.0	1.68	.00134	81	17.3	.094	.083	1.38	0
Average	...	...	...	...	1.74	......	...	15.6	.106	.093	1.35	...
Test 7:												
Reach A	49.0	68.2	0.72	30.5	2.24	0.00159	79	12.1	0.140	0.129	1.61	0
B	49.0	65.8	.74	29.8	2.21	.00171	79	12.1	.140	.129	1.64	0
C	49.0	61.2	.80	29.1	2.10	.00150	79	14.2	.117	.108	1.69	0
Average	...	...	...	...	2.18	......	...	12.8	.132	.122	1.65	...
Test 8:												
Reach A	60.7	83.4	0.73	32.4	2.57	0.00181	79	10.6	0.163	0.155	1.87	1
B	60.7	80.1	.76	32.0	2.50	.00191	79	11.0	.157	.148	1.90	0
C	60.7	73.8	.82	30.9	2.39	.00169	79	12.9	.132	.124	1.96	0
Average	...	...	...	...	2.49	......	...	11.5	.151	.142	1.91	...
Test 9:												
Reach A	21.0	54.4	0.39	28.6	1.90	0.000607	80	11.4	0.147	0.128	0.734	0
B	21.0	56.7	.37	28.8	1.97	.000600	80	10.8	.156	.137	.729	0
C	21.0	57.0	.37	28.4	2.00	.000427	80	12.6	.133	.118	.737	0
Average	...	...	...	...	1.96	......	...	11.6	.145	.128	.733	...

green and in full seed head. The stand was good, averaging 58 inches in height, with a minimum of 10 inches and a maximum of about 78 inches. Table 23 gives additional height data and stand counts. Figure 33 is a view of reach B of the channel, and figure 34 shows plants taken from the channel.

Nineteen tests, ranging in discharge rate from 3.8 to 61 ft³/s, were run. Three sill heights were used with each of the discharge rates with the exception of the second discharge rate, with which four sill heights were used. Table 24 gives the hydraulic data and friction factors for the tests. The Manning n values are plotted against the corresponding values of the hydraulic radius (R) in figure 35.

Cotton in channel FC 29

The cotton was planted lengthwise in the channel in rows 40 inches apart. When the tests were begun, the plants were green and in various stages of maturity, from blossom to boll. The stand was poor and thin, and plant height ranged from 4 to 40 inches, with an average of 21 inches. Plant width averaged

FIGURE 31.—Typical 'Hegari' sorghum plants from channel FC 30, experiment 2.

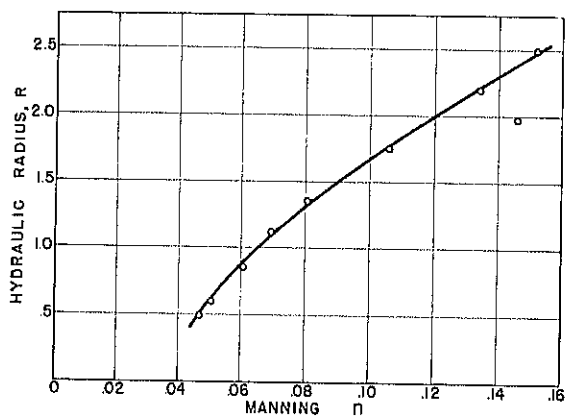

FIGURE 32.—Relation of Manning n to hydraulic radius (R) for flow tests on channel FC 30, experiment 2.

FIGURE 33.—'Hegari' sorghum in reach B of channel FC 30 during flow of 25.6 ft³/s, experiment 4. (Tall sorghum hides the water from view.)

TABLE 23.—*Stand counts and plant heights for 'Hegari' sorghum in channel FC 30, experiment 4*

Reach[1]	No. rows	No. stems per 10 feet of row	Average plant height (inches)	Average tallest plant[2] (inches)
A	14	16	52	58
B	14	24	61	67
C	14	20	60	67
Average for channel	14	20	58	64

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest plant was measured at 14 sampling points in each reach. The average of these measurements is the "average tallest plant."

TABLE 24.—*Hydraulic elements and friction factors for experiment 4,* 'Hegari' *sorghum in channel FC 30*

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	3.83	9.21	0.42	22.2	0.416	0.00147	76	16.8	0.076	0.053	0.173	0
B	3.83	8.61	.44	22.0	.393	.00127	76	19.9	.064	.046	.174	0
C	3.83	6.59	.58	21.8	.303	.00159	76	26.4	.046	.034	.176	0
Average	...	...	...	...	.371	......	...	21.0	.062	.044	.174	...
Test 2:												
Reach A	3.90	9.24	0.42	22.2	0.415	0.00151	76	16.8	0.076	0.053	0.175	0
B	3.90	8.73	.45	22.0	.396	.00119	76	20.5	.062	.045	.177	0
C	3.90	6.96	.56	21.8	.319	.00152	76	25.4	.048	.035	.178	0
Average	...	...	...	...	.377	......	...	20.9	.062	.044	.177	...
Test 3:												
Reach A	3.92	11.2	0.35	22.6	0.496	0.000953	76	16.1	0.082	0.058	0.174	0
B	3.92	12.9	.30	22.6	.570	.000473	76	18.4	.073	.054	.173	0
C	3.92	14.4	.27	23.3	.616	.000280	76	20.7	.066	.050	.168	0
Average	...	...	...	...	.561	......	...	18.4	.074	.054	.172	...
Test 4:												
Reach A	10.2	16.9	0.61	23.6	0.715	0.00155	76	18.2	0.077	0.060	0.433	0
B	10.2	16.1	.63	23.2	.695	.00133	76	20.8	.067	.053	.441	0
C	10.2	14.0	.73	22.9	.613	.00134	76	25.4	.054	.043	.447	0
Average	...	...	...	...	.674	......	...	21.5	.066	.052	.440	...
Test 5:												
Reach A	10.2	21.7	0.47	24.4	0.892	0.000820	76	17.3	0.085	0.067	0.417	0
B	10.2	23.8	.43	24.5	.971	.000573	76	18.2	.082	.065	.415	0
C	10.2	24.9	.41	24.5	1.02	.000407	76	20.0	.074	.061	.416	0
Average	...	...	...	...	.961	......	...	18.5	.080	.064	.416	...
Test 6:												
Reach A	10.5	16.4	0.64	23.5	0.701	0.00169	78	18.6	0.076	0.058	0.448	0
B	10.5	15.2	.69	23.1	.658	.00147	78	22.3	.062	.049	.456	0
C	10.5	12.0	.88	22.6	.530	.00194	78	27.3	.049	.039	.465	0
Average	...	...	...	...	.630	......	...	22.7	.062	.049	.456	...
Test 7:												
Reach A	10.6	17.4	0.61	23.7	0.737	0.00139	78	19.0	0.075	0.058	0.447	0
B	10.6	17.4	.61	23.4	.743	.00109	78	21.4	.066	.052	.452	0
C	10.6	16.5	.64	23.3	.709	.000913	78	25.2	.056	.045	.453	0
Average	...	...	...	...	.730	......	...	21.9	.066	.052	.451	...
Test 8:												
Reach A	16.9	22.0	0.76	24.3	0.907	0.00168	78	19.6	0.075	0.060	0.694	0
B	16.9	20.5	.82	24.0	.855	.00162	78	22.1	.066	.053	.703	0
C	16.9	16.9	1.00	23.5	.721	.00194	78	26.7	.053	.043	.720	0
Average	...	...	...	...	.828	......	...	22.8	.065	.052	.706	...
Test 9:												
Reach A	16.9	24.6	0.69	24.6	0.999	0.00131	78	19.0	0.078	0.064	0.688	0
B	16.9	24.3	.70	24.6	.990	.00108	78	21.3	.070	.057	.690	0
C	16.9	23.9	.71	24.4	.976	.000947	78	23.3	.064	.053	.692	0
Average	...	...	...	...	.988	......	...	21.2	.071	.058	.690	...

TABLE 24. — *Hydraulic elements and friction factors for experiment 4,* 'Hegari' *sorghum in channel FC 30* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 10:												
Reach A	17.0	34.4	0.49	26.1	1.32	0.000773	78	15.5	0.102	0.084	0.652	0
B	17.0	36.5	.46	26.3	1.39	.000580	78	16.4	.096	.081	.646	0
C	17.0	37.6	.45	26.1	1.44	.000467	78	17.4	.091	.078	.650	0
Average	...	...	...	...	1.38	......	...	16.4	.096	.081	.649	...
Test 11:												
Reach A	25.6	30.8	0.83	25.6	1.20	0.00163	78	18.8	0.082	0.069	1.00	0
B	25.6	29.4	.87	25.3	1.16	.00156	78	20.4	.076	.063	1.01	0
C	25.6	26.4	.97	24.8	1.07	.00152	78	23.9	.063	.053	1.03	0
Average	...	...	...	...	1.14	......	...	21.0	.074	.062	1.01	...
Test 12:												
Reach A	25.6	37.1	0.69	26.4	1.40	0.00129	75	16.2	0.097	0.083	0.965	0
B	25.6	37.4	.68	26.4	1.42	.00103	75	17.9	.088	.076	.972	0
C	25.6	36.9	.69	26.1	1.41	.000873	75	19.8	.080	.069	.978	0
Average	...	...	...	...	1.41	......	...	18.0	.088	.076	.972	...
Test 13:												
Reach A	25.7	46.4	0.55	27.8	1.67	0.00105	75	13.2	0.124	0.106	0.925	0
B	25.7	47.6	.54	27.7	1.71	.000760	75	15.0	.108	.095	.926	0
C	25.7	47.9	.54	27.4	1.74	.000653	75	16.0	.103	.090	.936	0
Average	...	...	...	...	1.71	......	...	14.7	.112	.097	.929	...
Test 14:												
Reach A	37.8	40.9	0.92	26.9	1.52	0.00219	75	16.0	0.100	0.086	1.40	0
B	37.8	37.3	1.01	26.5	1.41	.00208	75	18.7	.085	.073	1.42	0
C	37.8	32.0	1.18	25.5	1.25	.00207	75	23.2	.067	.057	1.48	0
Average	...	...	...	...	1.39	......	...	19.3	.084	.072	1.43	...
Test 15:												
Reach A	39.5	56.5	0.70	29.2	1.93	0.00140	72	13.5	0.122	0.110	1.35	50
B	39.5	55.9	.71	29.0	1.93	.00125	72	14.4	.114	.103	1.36	5
C	39.5	54.3	.73	28.4	1.92	.000980	72	16.8	.098	.089	1.40	0
Average	...	...	...	...	1.93	......	...	14.9	.111	.101	1.37	...
Test 16:												
Reach A	39.5	69.5	0.57	30.9	2.25	0.00102	72	11.9	0.143	0.131	1.28	70
B	39.5	70.3	.56	31.0	2.27	.000993	72	11.8	.144	.133	1.28	40
C	39.5	69.3	.57	30.4	2.28	.000720	72	14.1	.121	.112	1.30	0
Average	...	...	...	...	2.27	......	...	12.6	.136	.125	1.29	...
Test 17:												
Reach A	61.4	63.9	0.96	30.2	2.11	0.00225	72	13.9	0.120	0.111	2.02	60
B	61.4	58.9	1.04	29.4	2.00	.00242	72	15.0	.111	.101	2.08	30
C	61.4	52.1	1.18	28.1	1.85	.00211	72	18.9	.086	.079	2.19	0
Average	...	...	...	...	1.99	......	...	15.9	.106	.097	2.10	...
Test 18:												
Reach A	61.3	83.4	0.74	32.5	2.56	0.00142	72	12.2	0.142	0.135	1.88	80
B	61.3	82.3	.74	32.7	2.52	.00149	72	12.2	.142	.134	1.88	50
C	61.3	77.8	.79	31.3	2.48	.00128	72	14.0	.123	.116	1.95	10
Average	...	...	...	...	2.52	......	...	12.8	.136	.128	1.90	...

TABLE 24. — *Hydraulic elements and friction factors for experiment 4,* 'Hegari' *sorghum in channel FC 30* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 19:												
Reach A	61.1	89.2	0.69	33.5	2.66	0.00118	72	12.2	0.143	0.137	1.82	90
B	61.1	89.2	.69	33.9	2.63	.00131	72	11.7	.148	.142	1.80	60
C	61.1	85.5	.72	32.4	2.63	.00110	72	13.3	.130	.125	1.88	20
Average	...	...	...	...	2.64	......	...	12.4	.140	.135	1.83	...

FIGURE 34.—Typical 'Hegari' sorghum plants from channel FC 30, experiment 4. (Plants were placed 20 inches apart or the same as the channel row spacing.)

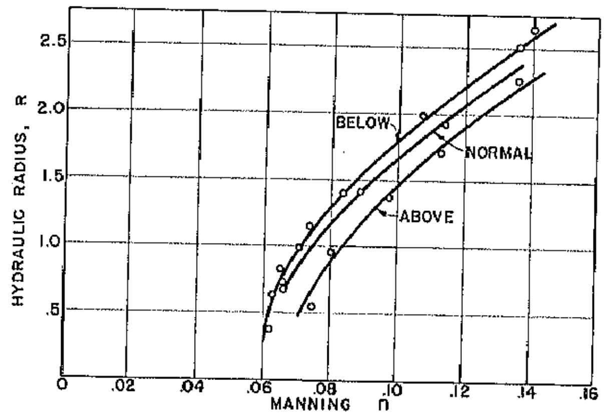

FIGURE 35.—Relation of Manning n to hydraulic radius (R) for flow tests on channel FC 30, experiment 4. (The three curves result from three flow-depth conditions—below normal, normal, and above normal.)

about 15 inches. Table 25 gives additional height data and stand counts. Figure 36 shows reach A during a flow test, and figure 37 shows typical plants from the channel.

Fifteen tests were run with six discharge rates, ranging from 3.7 to 60.0 ft³/s. Two sill heights were used with the smallest discharge rate and one sill height for the largest discharge rate. The remaining discharge rates had three sill heights. Table 26 gives the hydraulic elements and friction factors for the tests. The Manning n values are plotted against the cor-

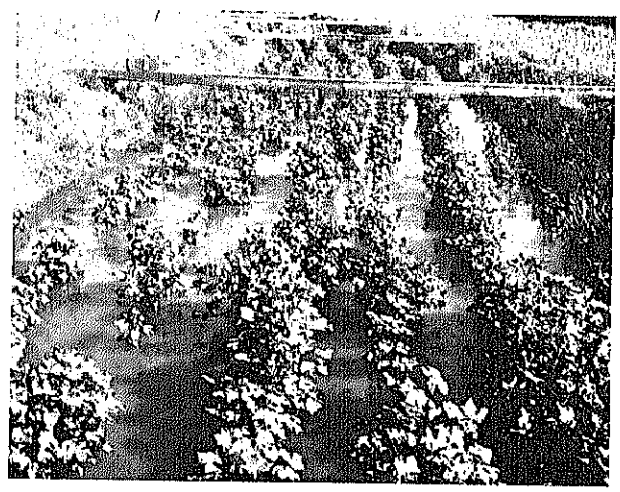

FIGURE 36.—Cotton in reach A of channel FC 29 during flow test 1, experiment 4. (Water depth is about 3 inches.)

TABLE 25.—*Stand counts and plant heights for cotton in channel FC 29, experiment 4*

Reach[1]	No. rows	No. stems per 10 feet of row	Average plant height (inches)	Average tallest plant[2] (inches)
A	7	13	20	26
B	7	10	18	22
C	7	13	26	32
Average for channel	7	12	21	27

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest plant was measured at 10 to 14 sampling points in each reach. The average of these measurements is the "average tallest plant."

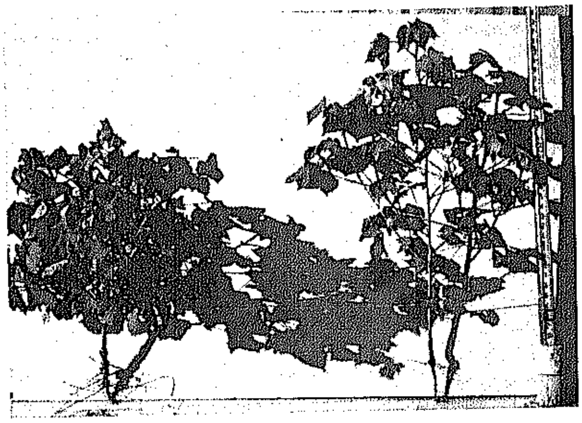

FIGURE 37.—Typical cotton plants from channel FC 29, experiment 4. (Plants were placed 40 inches apart or the same as the channel row spacing.)

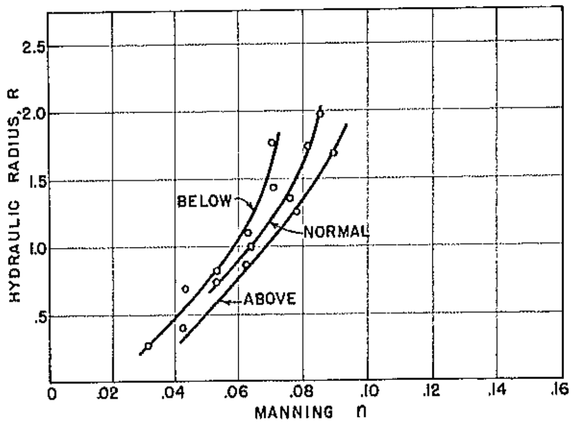

FIGURE 38.—Relation of Manning n to hydraulic radius (R) for flow tests on channel FC 29, experiment 4. (The three curves result from three flow-depth conditions—below normal, normal, and above normal.)

responding values of the hydraulic radius (R) in figure 38.

Experiment 6

Cotton in channel FC 29

The cotton was planted in 40-inch rows. When the tests were begun, the cotton was green and leafy and in the boll stage. The average height of the plants was 34 inches, with a few plants reaching 48 inches. The average width of the plants was about 32 inches. Table 27 gives additional height data and stand counts. Figure 39 shows reach B before the tests, and figure 40 shows a cross section of reach B after the tests.

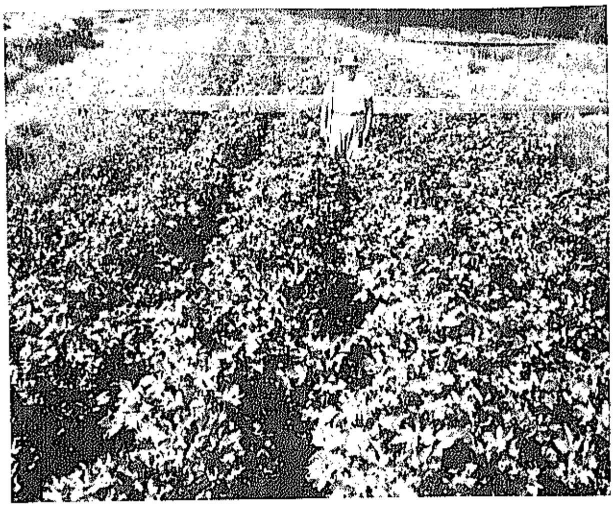

FIGURE 39.—Cotton in reach B of channel FC 29 before tests, experiment 6.

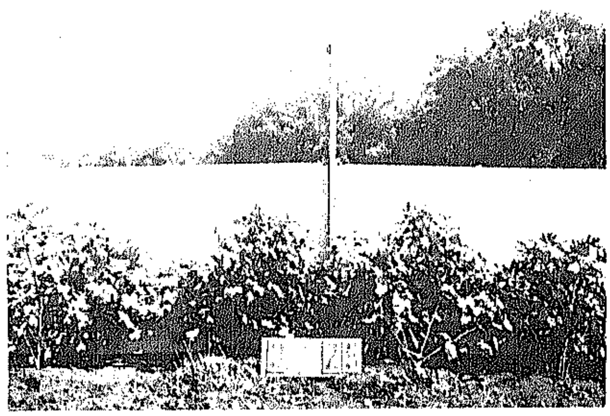

FIGURE 40.—Cotton across center of reach B of channel FC 29 after tests, experiment 6. (Plants in foreground were removed to show height and density of stand.)

TABLE 26. — *Hydraulic elements and friction factors for experiment 4, cotton in channel FC 29*

[*Q*, Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	3.75	5.25	0.71	20.7	0.254	0.00133	71	38.8	0.030	0.024	0.181	0
B	3.75	5.78	.65	20.6	.280	.00103	71	38.2	.032	.025	.182	0
C	3.75	5.25	.71	20.5	.256	.00147	71	36.8	.032	.025	.183	0
Average	...	...	...	...	.263	......	...	37.9	.031	.025	.182	...
Test 2:												
Reach A	3.76	6.63	0.57	21.0	0.316	0.000793	71	35.8	0.034	0.027	0.179	0
B	3.76	9.15	.41	21.0	.436	.000373	71	32.2	.040	.031	.179	0
C	3.76	11.0	.34	21.6	.510	.000353	71	25.4	.052	.040	.174	0
Average	...	...	...	...	.421	......	...	31.1	.042	.033	.177	...
Test 3:												
Reach A	10.9	12.6	0.87	22.1	0.570	0.00127	71	32.3	0.042	0.034	0.496	0
B	10.9	13.1	.83	21.7	.603	.00118	71	31.3	.044	.036	.503	0
C	10.9	11.7	.94	21.8	.536	.00171	71	30.9	.043	.035	.502	0
Average	...	...	...	...	.570	......	...	31.5	.043	.035	.500	...
Test 4:												
Reach A	10.9	15.0	0.73	22.4	0.670	0.000913	72	29.4	0.047	0.039	0.488	5
B	10.9	16.9	.65	22.4	.753	.000760	72	27.1	.052	.043	.489	5
C	10.9	17.5	.63	22.8	.765	.000913	72	23.7	.060	.048	.480	5
Average	...	...	...	...	.729	......	...	26.7	.053	.043	.486	...
Test 5:												
Reach A	11.0	17.9	0.61	23.0	0.778	0.000707	72	26.1	0.054	0.045	0.477	10
B	11.0	20.4	.54	23.1	.884	.000534	72	24.7	.059	.048	.476	5
C	11.0	21.8	.50	23.6	.924	.000666	72	20.3	.072	.058	.467	5
Average	...	...	...	...	.862	......	...	23.7	.062	.050	.473	...
Test 6:												
Reach A	17.7	19.5	0.91	23.2	0.843	0.00135	70	26.9	0.054	0.045	0.765	15
B	17.7	19.7	.90	23.0	.856	.00127	70	27.3	.053	.044	.770	5
C	17.7	17.8	1.00	22.9	.776	.00174	70	27.1	.052	.043	.774	5
Average	...	...	...	...	.825	......	...	27.1	.053	.044	.770	...
Test 7:												
Reach A	17.8	23.0	0.78	23.8	0.964	0.00105	70	24.3	0.061	0.051	0.747	20
B	17.8	24.4	.73	23.7	1.03	.000860	70	24.5	.061	.051	.751	10
C	17.8	24.2	.73	24.0	1.01	.00114	70	21.6	.069	.057	.741	5
Average	...	...	...	...	1.00	......	...	23.5	.064	.053	.746	...
Test 8:												
Reach A	17.8	28.9	0.62	24.6	1.17	0.000700	69	21.5	0.071	0.060	0.721	50
B	17.8	31.3	.57	24.8	1.26	.000580	69	21.0	.074	.063	.717	50
C	17.8	32.8	.54	25.3	1.30	.000733	69	17.6	.088	.074	.706	40
Average	...	...	...	...	1.24	......	...	20.0	.078	.066	.715	...
Test 9:												
Reach A	26.7	27.6	0.97	24.0	1.15	0.00145	69	23.7	0.064	.055	1.11	55
B	26.7	27.2	.98	24.2	1.12	.00139	69	24.8	.061	.052	1.10	60
C	26.7	24.8	1.08	24.1	1.03	.00203	69	23.6	.063	.053	1.11	45
Average	...	...	...	...	1.10	......	...	24.0	.063	.053	1.11	...

TABLE 26. — *Hydraulic elements and friction factors for experiment 4, cotton in channel FC 29* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 10:												
Reach A	26.6	33.4	0.80	25.3	1.32	0.00101	69	21.8	0.072	0.062	1.05	60
B	26.6	34.6	.77	25.2	1.38	.000900	69	21.8	.072	.063	1.06	70
C	26.6	34.7	.77	25.6	1.36	.00125	69	18.6	.085	.072	1.04	50
Average	...	...	...	...	1.35	......	...	20.7	.076	.066	1.05	...
Test 11:												
Reach A	26.6	43.1	0.62	26.8	1.61	0.000646	69	19.1	0.084	0.074	0.995	70
B	26.6	45.6	.58	26.9	1.70	.000467	69	20.7	.078	.070	.993	80
C	26.6	47.3	.56	27.3	1.73	.000734	69	15.8	.103	.091	.974	60
Average	...	...	...	...	1.68	......	...	18.5	.088	.078	.987	...
Test 12:												
Reach A	38.1	37.9	1.01	25.9	1.46	0.00139	69	22.4	0.071	0.062	1.47	80
B	38.1	37.4	1.02	25.6	1.46	.00127	69	23.7	.067	.060	1.49	90
C	38.1	35.4	1.08	25.6	1.38	.00198	69	20.7	.076	.066	1.49	65
Average	...	...	...	...	1.43	......	...	22.3	.071	.063	1.48	...
Test 13:												
Reach A	38.2	46.2	0.83	27.1	1.70	0.000900	68	21.1	0.077	0.069	1.40	95
B	38.2	47.6	.80	27.1	1.76	.000726	68	22.4	.073	.066	1.41	98
C	38.2	48.2	.79	27.4	1.76	.00114	68	17.7	.093	.082	1.39	70
Average	...	...	...	...	1.74	......	...	20.4	.081	.072	1.40	...
Test 14:												
Reach A	38.2	53.6	0.71	28.3	1.90	0.000586	68	21.4	0.078	0.070	1.35	95
B	38.2	56.2	.68	28.6	1.97	.000513	68	21.4	.078	.071	1.34	100
C	38.2	58.5	.65	28.8	2.03	.000753	68	16.7	.100	.091	1.33	80
Average	...	...	...	...	1.97	......	...	19.8	.085	.077	1.34	...
Test 15:												
Reach A	60.0	49.2	1.22	27.6	1.78	0.00141	66	24.4	0.068	0.061	2.17	98
B	60.0	48.7	1.23	27.3	1.79	.00122	66	26.3	.063	.057	2.20	100
C	60.0	46.4	1.29	27.1	1.71	.00224	66	20.8	.078	.070	2.21	85
Average	...	...	...	...	1.76	......	...	23.8	.070	.063	2.19	...

Seventeen tests were run with six discharge rates, ranging from 2.7 to 44.5 ft³/s. Three sill heights were used with all discharge rates except the smallest, with which only two sill heights were used. Table 28 gives the hydraulic elements and friction factors for the experiment. The Manning n values are plotted against the corresponding values of the hydraulic radius (R) in figure 41.

Sudangrass in channel FC 30

The seed were broadcast in the channel. When the tests were begun, the vegetation was tall and green and probably had reached its maximum bulk. The average length of the grass stems was 47 inches, but some of the tallest stems were 105 inches long. The lengths were measured along the stem and are not a measure of the cover height, since the grass tended to lean over. Table 29 gives additional length data and the stand counts. Figure 42 shows reach C before the tests, and figure 43 shows a cross section of the stand after the tests.

Twenty tests were run on this channel, with discharge rates ranging from 2.6 to 89.5 ft³/s. Three sill heights were used with most of the

(Continued on page 44.)

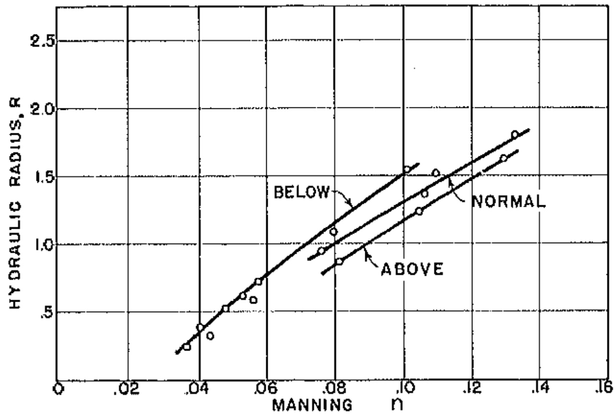

FIGURE 41.—Relation of Manning n to hydraulic radius (R) for flow tests on channel FC 29, experiment 6. (The three curves result from three flow-depth conditions—below normal, normal, and above normal.)

FIGURE 42.—Sudangrass in reach C of channel FC 30 before tests, experiment 6.

FIGURE 43.—Sudangrass across reach B of channel FC 30 after tests, experiment 6. (Grass in foreground was cut to show 3-ft-wide strip against background.)

TABLE 27.—*Stand counts and plant heights for cotton in channel FC 29, experiment 6*

Reach[1]	No. rows	No. stems per 10 feet of row	Average plant height (inches)	Average tallest plant[2] (inches)
A	6	17	30	36
B	6	24	32	36
C	6	30	39	42
Average for channel	6	24	34	38

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest plant was measured at each of several sampling points (usually 12) in each reach. The average of these measurements is the "average tallest plant."

TABLE 28. — *Hydraulic elements and friction factors for experiment 6, cotton in channel FC 29*

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	2.66	4.70	0.56	20.6	0.228	0.00114	80	35.0	0.033	0.025	0.129	0
B	2.66	5.22	.51	20.6	.254	.00103	80	31.4	.038	.028	.129	0
C	2.66	4.53	.59	20.4	.222	.00159	80	31.2	.037	.027	.130	0
Average	...	...	...	...	.235	......	...	32.5	.036	.027	.129	...
Test 2:												
Reach A	2.68	5.09	0.53	20.6	0.247	0.00103	80	33.0	0.036	0.027	0.130	0
B	2.68	6.48	.41	20.7	.313	.000600	80	30.2	.040	.030	.130	0
C	2.68	7.87	.34	21.0	.374	.000473	80	25.6	.049	.036	.128	0
Average	...	...	...	...	.311	......	...	29.6	.042	.031	.129	...
Test 3:												
Reach A	4.94	7.56	0.65	21.2	0.356	0.00112	80	32.8	0.038	0.030	0.233	0
B	4.94	7.97	.62	21.1	.378	.00115	80	29.8	.042	.033	.234	0
C	4.94	6.66	.74	21.0	.318	.00177	80	31.3	.039	.030	.236	0
Average	...	...	...	...	.351	......	...	31.3	.040	.031	.234	...
Test 4:												
Reach A	4.96	7.58	0.65	21.1	0.359	0.00110	80	32.9	0.038	0.030	0.235	0
B	4.96	8.18	.61	21.0	.389	.00105	80	30.0	.042	.033	.236	0
C	4.96	7.77	.64	21.1	.369	.00119	80	30.4	.041	.032	.235	0
Average	...	...	...	...	.372	......	...	31.1	.040	.032	.235	...
Test 5:												
Reach A	4.94	10.5	0.47	21.6	0.484	0.000594	80	27.8	0.047	0.037	0.228	0
B	4.94	12.7	.39	21.7	.586	.000453	80	23.8	.057	.044	.227	0
C	4.94	14.7	.34	22.5	.654	.000320	80	23.2	.060	.046	.219	0
Average	...	...	...	...	.575	......	...	24.9	.055	.042	.225	...
Test 6:												
Reach A	9.08	12.5	0.73	21.9	0.570	0.00135	76	26.2	0.052	0.041	0.415	0
B	9.08	11.8	.77	21.6	.547	.00149	76	26.9	.050	.039	.420	0
C	9.08	9.85	.92	21.4	.460	.00193	76	30.9	.042	.034	.420	0
Average	...	...	...	...	.526	......	...	28.0	.048	.038	.420	...
Test 7:												
Reach A	9.11	13.4	0.68	22.0	0.608	0.00122	76	25.0	0.055	0.043	0.415	0
B	9.11	13.4	.68	21.8	.613	.00121	76	25.0	.055	.043	.417	0
C	9.11	13.1	.69	21.9	.600	.00107	76	27.4	.050	.040	.416	0
Average	...	...	...	...	.607	......	...	25.8	.053	.042	.416	...
Test 8:												
Reach A	9.10	18.9	0.48	23.2	0.813	0.000820	76	18.7	0.077	0.060	0.392	0
B	9.10	20.2	.45	23.3	.868	.000780	76	17.3	.084	.066	.391	0
C	9.10	21.6	.42	23.6	.912	.000594	76	18.1	.081	.064	.385	0
Average	...	...	...	...	.864	......	...	18.0	.081	.063	.389	...
Test 9:												
Reach A	15.2	18.9	0.80	23.1	0.816	0.00171	76	21.5	0.067	0.054	0.656	0
B	15.2	16.7	.91	22.6	.740	.00198	76	23.7	.060	.048	.672	0
C	15.2	13.2	1.15	22.0	.598	.00233	76	30.8	.044	.036	.688	0
Average	...	...	...	...	.718	......	...	25.3	.057	.046	.672	...

,BLE 28. — *Hydraulic elements and friction factors for experiment 6, cotton in channel FC 29* — Continued

Discharge, ft^3/s. *A*, Area, ft^2. *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. ', Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	*Q*	*A*	*V*	*P*	*R*	*S*	°F	*C*	*n*	n_R	*VR*	%
it 10:												
Reach A	15.0	22.6	0.66	23.8	0.947	0.00130	74	18.9	0.078	0.063	0.630	2
B	15.0	22.3	.67	23.6	.942	.00139	74	18.6	.079	.064	.635	0
C	15.0	22.1	.68	23.7	.931	.00113	74	20.9	.071	.057	.632	0
Average	...	...	...	...	.940	......	...	19.5	.076	.061	.632	...
t 11:												
Reach A	15.1	29.4	0.51	24.7	1.19	0.000934	76	15.4	0.100	0.082	0.609	5
B	15.1	30.4	.50	24.6	1.24	.000934	76	14.6	.106	.087	.614	0
C	15.1	31.7	.48	25.2	1.26	.000800	76	15.0	.104	.085	.598	0
Average	...	...	...	...	1.23	......	...	15.0	.103	.085	.607	...
t 12:												
Reach A	22.7	28.8	0.79	24.6	1.17	0.00180	74	17.1	0.090	0.074	0.920	10
B	22.7	26.3	.86	24.2	1.09	.00206	74	18.2	.083	.068	.940	0
C	22.7	23.1	.98	23.9	.968	.00197	74	22.5	.066	.055	.950	0
Average	...	...	...	...	1.08	......	...	19.3	.080	.066	.937	...
t 13:												
Reach A	22.5	35.5	0.63	25.6	1.39	0.00136	72	14.6	0.108	0.091	0.880	30
B	22.5	34.8	.65	25.3	1.38	.00146	72	14.4	.109	.092	.891	5
C	22.5	33.7	.67	25.5	1.32	.00135	72	15.8	.099	.083	.879	0
Average	...	...	...	...	1.36	......	...	14.9	.105	.089	.883	...
t 14:												
Reach A	22.5	42.9	0.52	26.7	1.61	0.00107	74	12.6	0.128	0.110	0.884	40
B	22.5	43.4	.52	26.8	1.62	.00109	74	12.3	.132	.112	.839	20
C	22.5	44.0	.51	26.9	1.64	.00100	74	12.6	.128	.110	.838	5
Average	...	...	...	...	1.62	......	...	12.5	.129	.111	.840	...
; 15:												
Reach A	31.4	42.3	0.74	26.6	1.59	0.00181	74	13.8	0.116	0.100	1.18	40
B	31.4	39.9	.79	26.0	1.53	.00204	74	14.1	.114	.097	1.20	20
C	31.4	36.2	.87	25.6	1.41	.00201	74	16.3	.098	.082	1.22	5
Average	...	...	...	...	1.51	......	...	14.7	.109	.093	1.20	...
; 16:												
Reach A	31.4	50.9	0.62	27.9	1.82	0.00137	75	12.4	0.134	0.117	1.12	50
B	31.4	49.8	.63	27.6	1.80	.00149	75	12.2	.136	.118	1.14	30
C	31.4	48.7	.64	27.4	1.78	.00144	75	12.7	.129	.113	1.15	10
Average	...	...	...	...	1.80	......	...	12.4	0.133	.116	1.14	...
17:												
Reach A	44.5	47.6	0.93	27.4	1.74	0.00249	74	14.2	0.114	0.101	1.63	60
B	44.5	41.1	1.08	26.4	1.56	.00319	74	15.3	.104	.091	1.68	40
C	44.5	32.8	1.36	25.3	1.30	.00378	74	19.4	.080	.069	1.77	10
Average	...	...	...	...	1.53	......	...	16.3	.099	.087	1.69	...

discharge rates. Table 30 gives the hydraulic data and friction factors for the tests. The Manning n values for the experiment are plotted against the corresponding VR values in figure 44.

Experiment 8

Lespedeza in channel FC 29

Korean lespedeza was broadcast in the channel. When the tests were begun, the vegetation was green and in full leaf. The average plant height was about 8 inches, with a maximum of about 14 inches. The stand density was 122 stems per square foot. In addition to the lespedeza, there was a scattering of other plants with about the same average height (8 inches), but a few plants were 28 inches tall. These plants, mostly crabgrass, averaged about 28 stems per square foot. Table 31 gives the stand count and height data. For the lespedeza, a stand count is given for both the number of plants per square foot and the number of stems per square foot. A separate stand count (number of stems per square foot) and height data are included for crabgrass and barnyardgrass.

Figure 45 shows reach B before the tests. Figure 46 shows a closeup view of the lespedeza plants before the tests. The typical lespedeza

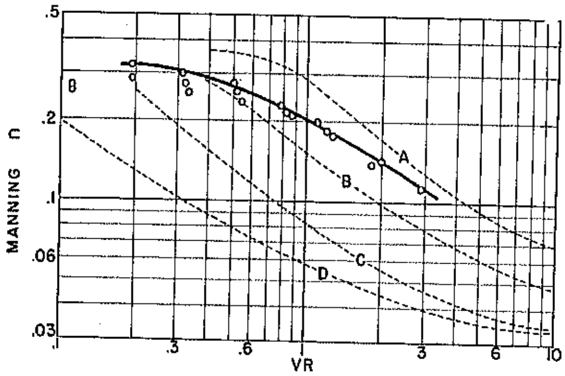

FIGURE 44.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 30, experiment 6.

TABLE 29.—*Stand counts and stem lengths for sudangrass in channel FC 30, experiment 6*

Reach[1]	Stem density (stems/ft²)	Average stem length (inches)	Average longest stem[2] (inches)
A	61	38	63
B	53	49	76
C	45	53	75
Average for channel	53	47	71

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The length of the longest stem was measured at 9 sampling points in each reach. The average of these measurements is the "average longest stem."

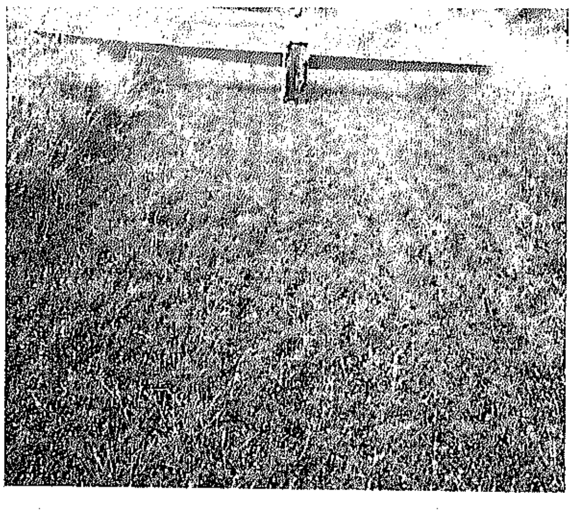

FIGURE 45.—Korean lespedeza in reach B of channel FC 29 before tests, experiment 8.

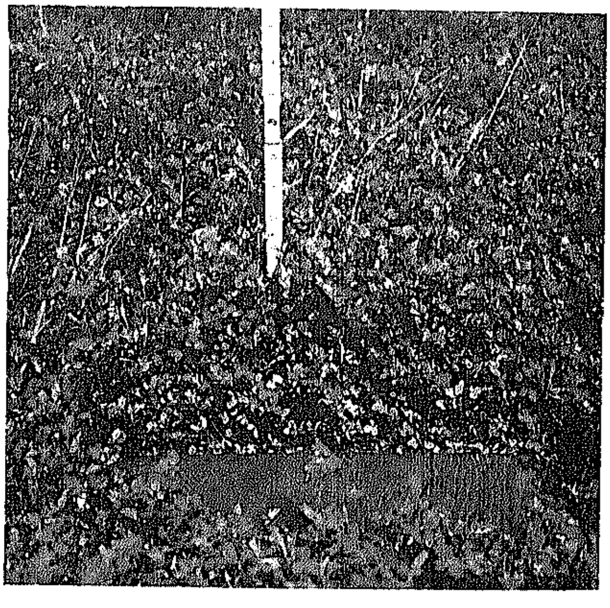

FIGURE 46.—Closeup view of Korean lespedeza in channel FC 29 before tests, experiment 8.

LE 30. —*Hydraulic elements and friction factors for experiment 6, sudangrass in channel FC 30*

Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
1:												
Reach A	2.60	16.5	0.16	23.5	0.703	0.00187	82	4.33	0.324	0.212	0.110	0
B	2.60	15.2	.17	23.3	.655	.00172	82	5.07	.275	.178	.111	0
C	2.60	11.3	.23	22.8	.493	.00217	82	7.03	.189	.119	.113	0
Average	...	...	...	...	.617	......	...	5.48	.263	.170	.111	...
2:												
Reach A	2.61	17.2	0.15	23.7	0.723	0.00169	82	4.35	0.325	0.214	0.110	0
B	2.61	16.7	.16	23.3	.718	.00137	82	5.01	.281	.187	.113	0
C	2.61	15.2	.17	23.4	.648	.00109	82	6.47	.214	.142	.111	0
Average	...	...	...	...	.696	......	...	5.28	.273	.181	.111	...
3:												
Reach A	4.78	24.5	0.20	24.8	0.987	0.00212	82	4.26	0.350	0.249	0.192	0
B	4.78	22.0	.22	24.1	.911	.00212	82	4.93	.298	.210	.198	0
C	4.78	16.1	.30	23.8	.677	.00288	82	6.73	.208	.140	.201	0
Average	...	...	...	...	.858	......	...	5.31	.285	.200	.197	...
4:												
Reach A	4.91	25.8	0.19	24.9	1.04	0.00154	80	4.75	0.317	0.230	0.198	0
B	4.91	25.5	.19	24.7	1.03	.00136	80	5.16	.291	.212	.199	0
C	4.91	24.3	.20	24.8	.980	.00109	80	6.18	.241	.175	.198	0
Average	...	...	...	...	1.02	......	...	5.36	.283	.206	.198	...
5:												
Reach A	4.99	31.0	0.16	25.6	1.21	0.00107	80	4.67	0.344	0.260	0.195	0
B	4.99	32.5	.15	25.6	1.27	.000813	80	4.76	.326	.250	.194	0
C	4.99	33.0	.15	25.7	1.28	.000653	80	5.22	.298	.229	.193	0
Average	...	...	...	...	1.25	......	...	4.82	.323	.246	.194	...
6:												
Reach A	8.40	31.1	0.27	25.5	1.22	0.00212	77	5.31	0.292	0.222	0.329	0
B	8.40	28.2	.30	25.1	1.12	.00229	77	5.86	.260	.195	.333	0
C	8.40	21.1	.40	24.2	.870	.00344	77	7.28	.201	.144	.346	0
Average	...	...	...	...	1.07	......	...	6.15	.251	.187	.336	...
7:												
Reach A	8.45	35.4	0.24	26.3	1.35	0.00156	77	5.19	0.303	0.237	0.321	0
B	8.45	35.2	.24	26.1	1.35	.00137	77	5.58	.282	.221	.324	0
C	8.45	33.1	.26	25.8	1.29	.00132	77	6.18	.252	.197	.329	0
Average	...	...	...	...	1.33	......	...	5.65	.279	.218	.325	...
8:												
Reach A	8.50	40.9	0.21	27.1	1.51	0.00113	79	5.03	0.319	0.256	0.314	10
B	8.50	42.5	.20	27.3	1.56	.000920	79	5.27	.306	.248	.312	10
C	8.50	42.3	.20	26.8	1.58	.000833	79	5.54	.291	.237	.318	0
Average	...	...	...	...	1.55	......	...	5.28	.305	.247	.315	...
9:												
Reach A	14.3	40.1	0.36	27.0	1.48	0.00231	79	6.12	0.262	0.210	0.530	10
B	14.3	36.7	.39	26.4	1.39	.00256	79	6.55	.241	.192	.544	10
C	14.3	27.3	.52	25.0	1.09	.00407	79	7.88	.193	.147	.572	0
Average	...	...	...	...	1.32	......	...	6.85	.232	.183	.549	...

TABLE 30. — *Hydraulic elements and friction factors for experiment 6, sudangrass in channel FC 30* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 10:												
Reach A	14.6	48.0	0.30	28.2	1.70	0.00132	81	6.42	0.255	0.213	0.517	30
B	14.6	48.8	.30	28.1	1.74	.00134	81	6.19	.265	.223	.520	25
C	14.6	45.6	.32	27.3	1.67	.00157	81	6.25	.261	.217	.534	0
Average	...	...	...	...	1.70	......	...	6.29	.260	.218	.524	...
Test 11:												
Reach A	14.6	54.8	0.27	29.0	1.88	0.000960	81	6.26	0.265	0.227	0.500	40
B	14.6	56.7	.26	29.0	1.95	.000953	81	5.96	.280	.242	.501	40
C	14.6	55.4	.26	28.3	1.96	.00109	81	5.69	.295	.254	.515	5
Average	...	...	...	...	1.93	......	...	5.97	.280	.241	.505	...
Test 12:												
Reach A	23.9	50.1	0.48	28.4	1.77	0.00203	81	7.94	0.208	0.177	0.842	50
B	23.9	47.0	.51	27.9	1.68	.00256	81	7.75	.212	.177	.853	40
C	23.9	36.1	.66	26.1	1.38	.00447	81	8.42	.188	.151	.912	5
Average	...	...	...	...	1.61	......	...	8.04	.203	.168	.869	...
Test 13:												
Reach A	24.1	58.5	0.41	29.4	1.99	0.00130	80	8.12	0.206	0.181	0.822	60
B	24.1	58.6	.41	29.2	2.01	.00147	80	7.56	.222	.195	.828	60
C	24.1	54.5	.44	28.2	1.93	.00175	80	7.62	.220	.190	.854	25
Average	...	...	...	...	1.98	......	...	7.77	.216	.189	.835	...
Test 14:												
Reach A	24.2	69.0	0.35	31.0	2.23	0.000873	80	7.93	0.215	0.194	0.780	75
B	24.2	71.4	.34	31.1	2.30	.000966	80	7.17	.240	.217	.777	75
C	24.2	69.8	.35	30.5	2.28	.00105	80	7.07	.243	.219	.789	10
Average	...	...	...	...	2.27	......	...	7.39	.233	.210	.782	...
Test 15:												
Reach A	36.6	59.3	0.62	29.7	1.99	0.00195	80	9.91	0.170	0.150	1.23	85
B	36.6	56.2	.65	28.9	1.94	.00263	80	9.12	.183	.160	1.26	70
C	36.6	45.0	.81	27.1	1.66	.00405	80	9.90	.165	.140	1.35	15
Average	...	...	...	...	1.86	......	...	9.64	.173	.150	1.28	...
Test 16:												
Reach A	36.8	68.9	0.53	30.9	2.23	0.00130	76	9.92	0.172	0.156	1.19	90
B	36.8	69.1	.53	30.8	2.25	.00160	76	8.86	.193	.175	1.20	85
C	36.8	64.1	.57	29.5	2.17	.00180	76	9.19	.186	.167	1.25	15
Average	...	...	...	...	2.22	......	...	9.32	.184	.166	1.21	...
Test 17:												
Reach A	35.9	82.5	0.44	32.6	2.53	0.000793	76	9.71	0.179	0.168	1.10	95
B	35.9	85.3	.42	32.8	2.60	.000993	76	8.29	.212	.198	1.09	90
C	35.9	82.8	.43	32.1	2.58	.00104	76	8.38	.209	.195	1.12	30
Average	...	...	...	...	2.57	......	...	8.79	.200	.187	1.10	...
Test 18:												
Reach A	59.5	70.2	0.85	31.1	2.26	0.00188	76	13.0	0.132	0.121	1.92	98
B	59.5	66.9	.89	30.5	2.20	.00279	76	11.4	.150	.126	1.96	95
C	59.5	54.1	1.10	28.1	1.92	.00418	76	12.3	.136	.120	2.11	40
Average	...	...	...	...	2.13	......	...	12.2	.139	.126	2.00	...

TABLE 30. — *Hydraulic elements and friction factors for experiment 6, sudangrass in channel FC 30* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 19:												
Reach A	59.5	83.5	0.71	33.2	2.51	0.00117	76	13.2	0.133	0.124	1.79	98
B	59.5	84.2	.71	33.1	2.55	.00107	76	13.5	.130	.122	1.80	98
C	59.5	78.4	.76	31.5	2.49	.00171	76	11.6	.151	.140	1.89	50
Average	...	...	...	...	2.52	......	...	12.8	.138	.129	1.83	...
Test 20:												
Reach A	89.5	78.2	1.14	32.1	2.44	0.00194	76	16.6	0.104	0.098	2.78	100
B	89.5	74.1	1.21	31.6	2.34	.00288	76	14.8	.116	.108	2.83	99
C	89.5	58.9	1.52	28.9	2.04	.00467	76	15.6	.107	.098	3.10	70
Average	...	...	...	...	2.27	......	...	15.7	.109	.101	2.90	...

TABLE 31.—*Stand counts and plant heights for Korean lespedeza and annual grasses in channel FC 29, experiment 8*

Reach[1]	Korean lespedeza				Annual grasses		
	No. plants per ft²	No. stems per ft²	Average plant height (inches)	Average tallest plant[2] (inches)	No. stems per ft²	Average plant height (inches)	Average tallest plant[2] (inches)
A	41	153	8	11	20	9	14
B	36	136	8	12	12	10	15
C	24	78	9	13	18	8	12
Average for channel	34	122	8	12	17	9	14

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The height of the tallest plant was measured at 9 sampling points in each reach. The average of these measurements is the "average tallest plant."

plants in figure 47 show five or six principal branches near the base. These branches are reported as stems in the count.

Seventeen tests were run on the channel, ranging in discharge rate from 1.1 to 63.8 ft³/s. Three sill heights were used with most of the discharge rates. Table 32 gives the hydraulic elements and friction factors for the tests. The Manning n values are plotted against the corresponding values of VR in figure 48. The two envelope curves contain all points for below normal, normal, and above-normal depth flows.

Lovegrass in channel FC 30

Lovegrass was broadcast in the channel.

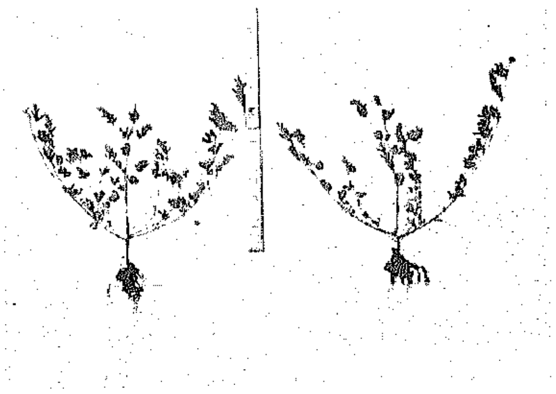

FIGURE 47.—Korean lespedeza plants removed from channel FC 29 before tests.

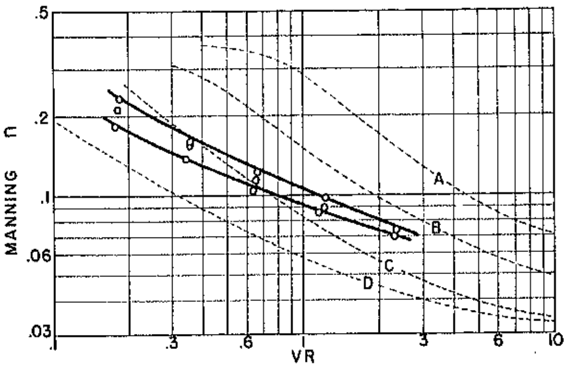

FIGURE 48.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 29, experiment 8.

When the tests were begun, the grass was still green. The seed heads were still on, but they had already dropped the seed. The stems averaged 12 inches in length, with some stems 32 inches long. In addition to the lovegrass, there was a considerable amount of crabgrass in the channel. The crabgrass averaged 22 inches in length, with a maximum of 50 inches. Table 33 gives the stand count and height data. Separate counts are given for the lovegrass (number of plants per square foot) and for the crabgrass (number of stems per square foot). Figure 49 shows reach B before the tests, and figure 50 shows a cross section of the reach. Figure 51 is a photograph of a typical plant from the channel.

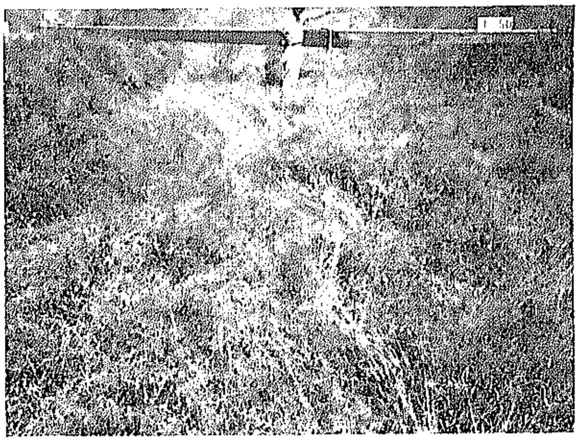

FIGURE 49.—Lovegrass in reach B of channel FC 30 before tests, experiment 8.

FIGURE 50.—Lovegrass across reach B of channel FC 30, experiment 8. (Grass in foreground was cut to show 2-ft-wide strip against background.)

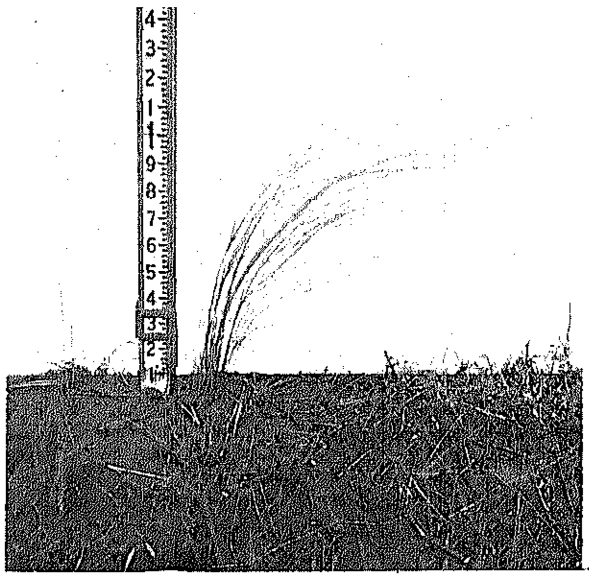

FIGURE 51.—Typical lovegrass plant in channel FC 30 after tests, experiment 8.

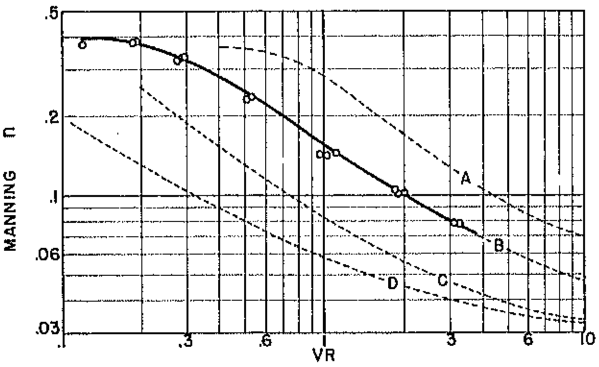

FIGURE 52.—Relation of Manning n to product of velocity and hydraulic radius (VR) for flow tests on channel FC 30, experiment 8.

TABLE 32.—*Hydraulic elements and friction factors for experiment 8, Korean lespedeza in channel FC 29*

[Q, Discharge, ft³/s. *A*, Area, ft². *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A......	2.03	14.0	0.14	22.3	0.631	0.00133	71	4.97	0.278	0.179	0.091	85
B......	2.03	13.4	.15	21.8	.616	.00157	71	4.85	.283	.181	.093	80
C......	2.03	12.0	.17	21.5	.557	.00258	71	4.45	.303	.188	.094	55
Average.....	...	...	...	...	.601	......	...	4.76	.288	.183	.093	...
Test 2:												
Reach A......	2.04	14.3	0.14	22.2	0.645	0.00132	75	4.86	0.285	0.184	0.092	85
B......	2.04	13.8	.15	21.8	.632	.00143	75	4.92	.280	.181	.094	80
C......	2.04	14.0	.15	21.8	.639	.00140	75	4.88	.285	.183	.093	75
Average.....	...	...	...	...	.639	......	...	4.89	.283	.183	.093	...
Test 3:												
Reach A......	1.13	11.0	0.10	21.6	0.506	0.00139	78	3.92	0.339	0.202	0.053	35
B......	1.13	10.1	.11	21.2	.478	.00157	78	4.09	.325	.190	.054	30
C......	1.13	9.36	.12	21.0	.446	.00195	78	4.10	.317	.184	.054	25
Average.....	...	...	...	...	.477	......	...	4.04	.327	.192	.054	...
Test 4:												
Reach A......	4.12	18.5	0.22	22.7	0.813	0.00135	74	6.73	0.214	0.150	0.181	[1]85
B......	4.12	17.9	.23	22.5	.792	.00148	74	6.72	.214	.149	.182	85
C......	4.12	16.4	.25	22.1	.739	.00257	74	5.78	.245	.166	.186	85
Average.....	...	...	...	...	.781	......	...	6.41	.224	.155	.183	...
Test 5:												
Reach A......	4.15	18.7	0.22	23.0	0.814	0.00125	71	6.95	0.207	0.146	0.181	90
B......	4.15	18.6	.22	22.8	.816	.00128	71	6.93	.210	.146	.182	90
C......	4.15	19.0	.22	22.7	.838	.00128	71	6.68	.217	.153	.184	90
Average.....	...	...	...	...	.823	......	...	6.85	.211	.148	.182	...
Test 6:												
Reach A......	4.17	21.1	0.20	23.3	0.905	0.000694	74	7.86	0.187	0.136	0.178	90
B......	4.17	23.4	.18	23.6	.989	.000420	74	8.73	.170	.127	.176	90
C......	4.17	27.2	.15	24.3	1.12	.000240	74	9.33	.162	.125	.171	90
Average.....	...	...	...	...	1.00	......	...	8.64	.173	.129	.175	...
Test 7:												
Reach A......	8.37	23.8	0.35	23.9	0.996	0.00131	75	9.74	0.153	0.116	0.351	95
B......	8.37	23.4	.36	23.6	.992	.00143	75	9.51	.157	.119	.355	95
C......	8.37	22.7	.37	23.6	.960	.00181	75	8.84	.168	.125	.354	95
Average.....	...	...	...	...	.983	......	....	9.36	.159	.120	.353	...
Test 8:												
Reach A......	8.38	24.1	0.35	23.9	1.00	0.00125	76	9.83	0.152	0.115	0.348	95
B......	8.38	24.1	.35	23.7	1.02	.00123	76	9.32	.152	.116	.355	95
C......	8.38	24.7	.34	24.0	1.03	.00125	76	9.44	.159	.121	.349	95
Average.....	...	...	...	...	1.02	......	...	9.70	.154	.117	.351	...
Test 9:												
Reach A......	8.40	27.5	0.30	24.3	1.13	0.000680	75	11.0	0.138	0.109	0.345	95
B......	8.40	29.7	.23	24.4	1.22	.000467	75	11.8	.130	.104	.344	95
C......	8.40	33.4	.25	25.2	1.33	.000340	75	11.9	.132	.107	.335	95
Average.....	...	...	...	...	1.23	......	...	11.6	.133	.107	.341	...

See footnote at end of table.

TABLE 32. — *Hydraulic elements and friction factors for experiment 8, Korean lespedeza in channel FC 29* — Continued

[Q, Discharge, ft³/s. A, Area, ft². V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 10:												
Reach A	16.0	29.4	0.54	24.6	1.19	0.00143	72	13.2	0.117	0.094	0.649	98
B	16.0	28.1	.57	24.2	1.16	.00166	72	11.8	.130	.103	.659	98
C	16.0	25.9	.62	24.0	1.08	.00259	72	11.7	.130	.102	.667	98
Average	...	...	...	...	1.14	......	...	12.2	.126	.100	.658	...
Test 11:												
Reach A	16.0	30.3	0.53	24.7	1.22	0.00121	73	13.8	0.112	0.091	0.647	100
B	16.0	30.3	.53	24.6	1.24	.00116	73	13.9	.111	.091	.655	100
C	16.0	31.2	.51	24.6	1.26	.00117	73	13.4	.116	.095	.648	100
Average	...	...	...	...	1.24	......	...	13.7	.113	.092	.650	...
Test 12:												
Reach A	16.0	34.6	0.46	25.3	1.37	0.000693	74	15.0	0.105	0.088	0.634	100
B	16.0	36.8	.44	25.4	1.45	.000520	74	15.9	.100	.085	.632	100
C	16.0	40.4	.40	26.1	1.55	.000420	74	15.6	.103	.088	.615	100
Average	...	...	...	...	1.46	......	...	15.5	.103	.087	.627	...
Test 13:												
Reach A	31.3	37.6	0.83	25.9	1.45	0.00158	74	17.4	0.092	0.078	1.21	100
B	31.3	35.6	.88	25.3	1.41	.00187	74	17.1	.093	.079	1.24	100
C	31.3	32.6	.96	24.8	1.31	.00299	74	15.3	.103	.085	1.26	100
Average	...	...	...	...	1.39	......	...	16.6	.096	.081	1.24	...
Test 14:												
Reach A	31.5	39.5	0.80	26.0	1.52	0.00131	73	17.9	0.090	0.077	1.21	100
B	31.5	39.0	.81	25.7	1.52	.00129	73	18.2	.088	.076	1.23	100
C	31.5	39.4	.80	26.0	1.52	.00136	73	17.6	.091	.079	1.21	100
Average	...	...	...	...	1.52	......	...	17.9	.090	.077	1.22	...
Test 15:												
Reach A	31.4	44.4	0.71	26.9	1.65	0.000840	73	19.0	0.086	0.075	1.16	100
B	31.4	46.1	.68	27.0	1.71	.000700	73	19.7	.083	.074	1.16	100
C	31.4	49.1	.64	27.5	1.78	.000620	73	19.2	.085	.076	1.14	100
Average	...	...	...	...	1.71	......	...	19.3	.085	.075	1.15	...
Test 16:												
Reach A	63.7	50.1	1.27	27.8	1.80	0.00175	73	22.6	0.073	0.066	2.29	100
B	63.7	47.1	1.35	27.3	1.73	.00205	73	22.7	.072	.065	2.34	100
C	63.7	43.2	1.47	26.7	1.62	.00272	73	22.2	.073	.065	2.38	100
Average	...	...	...	...	1.72	......	...	22.5	.073	.065	2.34	...
Test 17:												
Reach A	63.8	52.6	1.21	28.1	1.88	0.00141	74	23.5	0.071	0.064	2.27	100
B	63.8	51.7	1.23	27.7	1.86	.00145	74	23.7	.070	.064	2.29	100
C	63.8	51.5	1.24	27.8	1.86	.00145	74	23.9	.070	.063	2.31	100
Average	...	...	...	...	1.87	......	...	23.7	.070	.064	2.29	...

[1] All lespedeza in subsequent tests was submerged; grass was the unsubmerged vegetation.

TABLE 33.—*Stand counts and stem lengths for lovegrass and crabgrass in channel FC 30, experiment 8*

Reach[1]	Lovegrass			Crabgrass		
	No. plants per ft^2 *	Average stem length (inches)	Average longest stem[2] (inches)	No. stems per ft^2	Average stem length (inches)	Average longest stem[2] (inches)
A	9	11	19	94	22	35
B	10	12	21	67	23	38
C	10	14	23	35	21	36
Average for channel	10	12	21	65	22	36

[1] Reach A extends from station 1+00 to station 2+50, reach B extends from station 2+50 to station 4+00, and reach C extends from station 4+00 to station 5+50. (See figure 1.)

[2] The length of the longest stem was measured at 9 sampling points in each reach. The average of these measurements is the "average longest stem."

* Each plant had about 10 stems of very small diameter.

Eighteen tests, ranging in discharge rate from 2.8 to 99.5 ft^3/s, were run. Several sill heights were used with each discharge rate except the smallest rate. Table 34 gives the hydraulic data and friction factors for the experiment. The Manning *n* values for the tests are plotted against the corresponding values of *VR* in figure 52.

ANALYSIS

If the need arises for an *n* value for a channel exactly like one of those tested, the reported *n* values can be applied directly, but this situation is almost never the case. The channel or flood plain under study will differ from the test channel being used as a guide for the selection of *n*. The value of *n* for the test channel can serve as a base value to which corrections must be applied to adjust for the differences between the test channel and the channel for which an estimate of *n* is needed. Unfortunately, not enough test data are available to isolate the effect of each variable that influences the *n* value, and the adjustment cannot be reduced to a mechanical procedure. Instead, the adjustment must be based on judgment.

Influence of Plant Shape on Friction Factor

The right graph in figure 53 shows that the *n* value for 'Redlan Kafir' increased with depth, at least to the depth tested. To the left of this graph, and to the same scale, is a photograph of a typical plant from channel FC 29. A comparison of the photograph and the graph yields the conclusion that the *n* value increased with the depth because of the greater bulk of vegetation in the flow path. For deeper flows the leaves would have been overtopped, resulting in a reversal or decrease in the *n* value.

The left graph shows the velocity distribution in the vertical in the center of the channel during a flow of 38 ft^3/s. The velocity increased from bottom to top as expected, but the distribution was distorted by the vegetation in the flow stream. Near the bed, where there were only a few relatively bare stalks, the velocity increased rapidly with distance from the bed. At the level of the first branching leaves, the rate of increase in the velocity was greatly reduced. Above the leaves an increase in the velocity occurred again, until the water surface approached the top leaves, and then the friction at the air-water interface began to affect the velocity. Therefore, the shape of a plant and its leaf size and distribution determine the extent of velocity reduction and the corresponding effect on the friction factor.

Influence of Row Spacing on Friction Factor

Two row spacings, 7 inches and 14 inches, were tested for wheat, and the friction factors were compared. The first comparison was made with a poor-quality stand, so another comparison was made 2 years later after tests with a

(Continued on page 54.)

TABLE 34. — *Hydraulic elements and friction factors for experiment 8, lovegrass in channel FC 30*

[Q, Discharge, ft^3/s. A, Area, ft^2. V, Velocity, ft/s. P, Wetted perimeter, ft. R, Hydraulic radius, ft. S, Slope, ft/ft. °F, Water temperature. C, Coefficient in Chezy formula. n, Manning n friction factor. n_k, Coefficient in Kutter formula. VR, Product of V and R. %, Degree of submergence]

Flow test and channel reach	Q	A	V	P	R	S	°F	C	n	n_k	VR	%
Test 1:												
Reach A	2.82	20.9	0.14	24.0	0.872	0.00147	77	3.77	0.387	0.265	0.118	0
B	2.82	19.9	.14	23.6	.841	.00178	77	3.67	.397	.268	.119	0
C	2.82	13.8	.20	22.2	.623	.00302	77	4.70	.294	.187	.127	0
Average	. . .	. . .	. . .	. . .	.779	. . . . . .	. . .	4.05	.359	.240	.121	. . .
Test 2:												
Reach A	4.77	28.3	0.17	25.0	1.13	0.00157	78	3.98	0.382	0.282	0.190	0
B	4.77	26.6	.18	24.8	1.07	.00207	78	3.82	.395	.287	.193	0
C	4.77	18.6	.26	23.4	.796	.00378	78	4.67	.308	.209	.204	0
Average	. . .	. . .	. . .	. . .	.999	. . . . . .	. . .	4.16	.362	.259	.196	. . .
Test 3:												
Reach A	4.79	29.2	0.16	25.3	1.15	0.00152	80	3.92	0.389	0.288	0.189	0
B	4.79	28.0	.17	25.0	1.12	.00177	80	3.84	.397	.291	.192	0
C	4.79	22.5	.21	24.3	.927	.00241	80	4.50	.326	.231	.197	0
Average	. . .	. . .	. . .	. . .	1.07	. . . . . .	. . .	4.09	.371	.270	.193	. . .
Test 4:												
Reach A	4.82	31.5	0.15	25.6	1.23	0.00119	79	4.00	0.387	0.291	0.188	10
B	4.82	31.9	.15	25.6	1.25	.00121	79	3.88	.400	.302	.189	0
C	4.82	29.9	.16	25.3	1.18	.00122	79	4.24	.363	.271	.190	0
Average	. . .	. . .	. . .	. . .	1.22	. . . . . .	. . .	4.04	.383	.288	.189	. . .
Test 5:												
Reach A	7.73	36.7	0.21	26.4	1.39	0.00142	77	4.72	0.335	0.262	0.292	25
B	7.73	35.8	.22	26.1	1.37	.00161	77	4.60	.344	.267	.296	5
C	7.73	30.8	.25	25.5	1.21	.00227	77	4.79	.323	.244	.304	5
Average	. . .	. . .	. . .	. . .	1.32	. . . . . .	. . .	4.70	.334	.258	.297	. . .
Test 6:												
Reach A	7.77	40.0	0.19	26.8	1.49	0.00107	79	4.86	0.329	0.263	0.289	40
B	7.77	40.7	.19	26.8	1.52	.00109	79	4.69	.341	.274	.290	10
C	7.77	38.9	.20	26.5	1.47	.00113	79	4.91	.326	.259	.294	10
Average	. . .	. . .	. . .	. . .	1.49	. . . . . .	. . .	4.82	.332	.265	.291	. . .
Test 7:												
Reach A	7.78	45.8	0.17	27.7	1.65	0.000693	81	5.02	0.323	0.266	0.280	50
B	7.78	48.2	.16	28.0	1.72	.000613	81	4.99	.328	.272	.279	30
C	7.78	48.8	.16	27.5	1.78	.000560	81	5.07	.324	.272	.285	20
Average	. . .	. . .	. . .	. . .	1.72	. . . . . .	. . .	5.03	.325	.270	.281	. . .
Test 8:												
Reach A	14.6	44.5	0.33	27.6	1.61	0.00135	76	7.03	0.231	0.191	0.528	60
B	14.6	43.9	.33	27.3	1.61	.00158	76	6.58	.247	.203	.535	45
C	14.6	39.8	.37	26.7	1.49	.00192	76	6.86	.234	.189	.547	30
Average	. . .	. . .	. . .	. . .	1.57	. . . . . .	. . .	6.82	.237	.194	.537	. . .
Test 9:												
Reach A	14.7	46.9	0.31	27.8	1.68	0.00111	77	7.24	0.225	0.189	0.526	65
B	14.7	47.5	.31	27.8	1.70	.00125	77	6.70	.244	.204	.525	55
C	14.7	45.4	.32	27.3	1.66	.00129	77	6.98	.233	.194	.536	40
Average	. . .	. . .	. . .	. . .	1.68	. . . . . .	. . .	6.97	.234	.196	.529	. . .

TABLE 34. — *Hydraulic elements and friction factors for experiment 8, lovegrass in channel FC 30* — Continued

[*Q*, Discharge, ft^3/s. *A*, Area, ft^2. *V*, Velocity, ft/s. *P*, Wetted perimeter, ft. *R*, Hydraulic radius, ft. *S*, Slope, ft/ft. °F, Water temperature. *C*, Coefficient in Chezy formula. *n*, Manning *n* friction factor. n_k, Coefficient in Kutter formula. *VR*, Product of *V* and *R*. %, Degree of submergence]

Flow test and channel reach	*Q*	*A*	*V*	*P*	*R*	*S*	°F	*C*	*n*	n_k	*VR*	%
Test 10:												
Reach A	14.7	53.0	0.28	28.7	1.85	0.000747	77	7.44	0.222	0.191	0.512	75
B	14.7	55.3	.26	28.9	1.91	.000760	77	6.96	.239	.206	.506	65
C	14.7	55.4	.26	28.4	1.95	.000707	77	7.14	.235	.203	.517	30
Average	...	...	...	...	1.90	......	...	7.18	.232	.200	.512	...
Test 11:												
Reach A	31.2	51.9	0.60	28.4	1.82	0.00150	76	11.5	0.143	0.125	1.10	90
B	31.2	50.9	.61	28.2	1.81	.00173	76	11.0	.151	.130	1.11	90
C	31.2	46.5	.67	27.3	1.70	.00186	76	11.9	.137	.118	1.14	90
Average	...	...	...	...	1.78	......	...	11.5	.144	.124	1.12	...
Test 12:												
Reach A	30.2	58.1	0.52	29.6	1.97	0.000960	75	11.9	0.141	0.125	1.02	100
B	30.2	59.8	.50	29.6	2.02	.000987	75	11.3	.149	.132	1.02	100
C	30.2	59.0	.51	28.9	2.04	.000847	75	12.3	.137	.123	1.04	100
Average	...	...	...	...	2.01	......	...	11.8	.142	.127	1.03	...
Test 13:												
Reach A	30.2	67.0	0.45	30.7	2.18	0.000640	76	12.1	0.141	0.128	0.983	100
B	30.2	70.2	.43	31.1	2.26	.000587	76	11.8	.145	.133	.974	100
C	30.2	70.7	.43	30.6	2.31	.000540	76	12.1	.142	.130	.986	100
Average	...	...	...	...	2.25	......	...	12.0	.143	.130	.981	...
Test 14:												
Reach A	59.3	62.3	0.95	30.2	2.06	0.00159	75	16.6	0.102	0.092	1.96	100
B	59.3	60.7	.98	29.8	2.04	.00179	75	16.2	.104	.094	1.99	100
C	59.3	56.0	1.06	28.4	1.97	.00189	75	17.4	.096	.087	2.09	100
Average	...	...	...	...	2.02	......	...	16.7	.101	.091	2.01	...
Test 15:												
Reach A	59.3	68.2	0.87	31.0	2.20	0.00121	75	16.8	0.102	0.093	1.91	100
B	59.3	68.9	.86	31.0	2.22	.00125	75	16.3	.104	.097	1.91	100
C	59.3	66.6	.89	30.1	2.21	.00117	75	17.6	.097	.090	1.97	100
Average	...	...	...	...	2.21	......	...	16.9	.101	.093	1.93	...
Test 16:												
Reach A	59.6	77.9	0.76	31.9	2.44	0.000840	74	16.9	0.103	0.096	1.87	100
B	59.6	80.2	.74	32.4	2.47	.000887	74	15.9	.109	.103	1.84	100
C	59.6	79.4	.75	31.4	2.53	.000767	74	17.0	.103	.097	1.90	100
Average	...	...	...	...	2.48	......	...	16.6	.105	.099	1.87	...
Test 17:												
Reach A	99.5	72.9	1.36	31.4	2.32	0.00161	75	22.2	0.077	0.073	3.16	100
B	99.5	71.0	1.40	31.4	2.26	.00189	75	21.4	.080	.075	3.16	100
C	99.5	65.5	1.52	30.0	2.18	.00198	75	23.1	.074	.069	3.31	100
Average	...	...	...	...	2.25	......	...	22.2	.077	.072	3.21	...
Test 18:												
Reach A	99.5	80.4	1.24	32.3	2.48	0.00119	75	22.8	0.076	0.072	3.08	100
B	99.5	80.4	1.24	32.5	2.47	.00140	75	21.1	.082	.078	3.06	100
C	99.5	77.3	1.29	31.2	2.47	.00125	75	23.2	.074	.071	3.19	100
Average	...	...	...	...	2.47	......	...	22.4	.077	.074	3.11	...

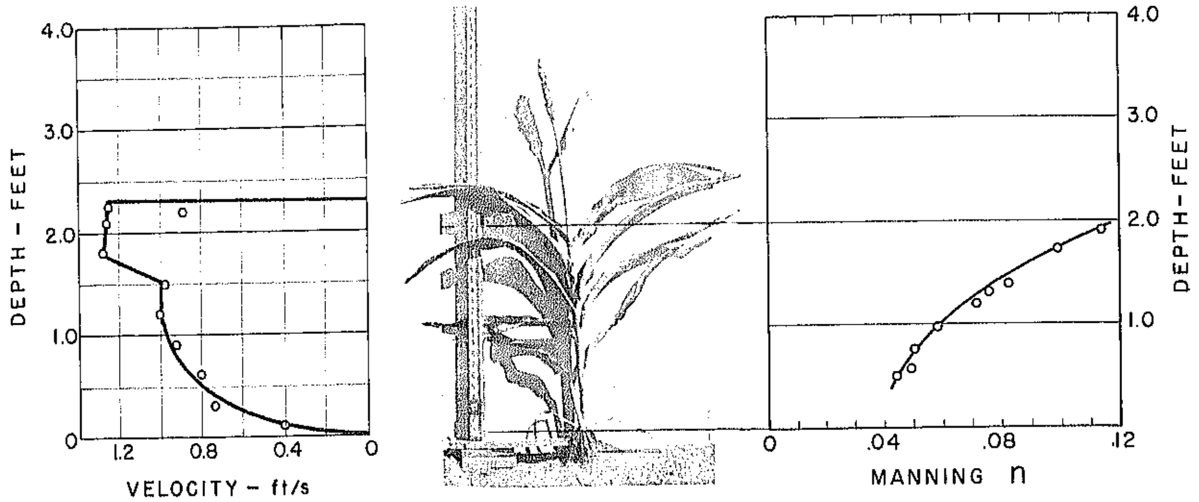

FIGURE 53.—Variation of velocity with depth for a vertical in channel FC 29 during flow of 38 ft^3/s, experiment 2.

very good stand. The results for the poor-quality stand, as revealed by the n–VR curves (figs. 11 and 14), show no difference between the friction factors for the two spacings for the deep flows. Figures 23 and 26 show similar results for the deep flows in the channels with the very good stands. However, for the shallow flows there was a difference that is best shown by an n-hydraulic radius plotting. The graphs for the four channels for this plotting are shown in figure 54. They permit easy comparisons of the row spacings as well as the cover qualities.

The n versus R points are considerably scat-

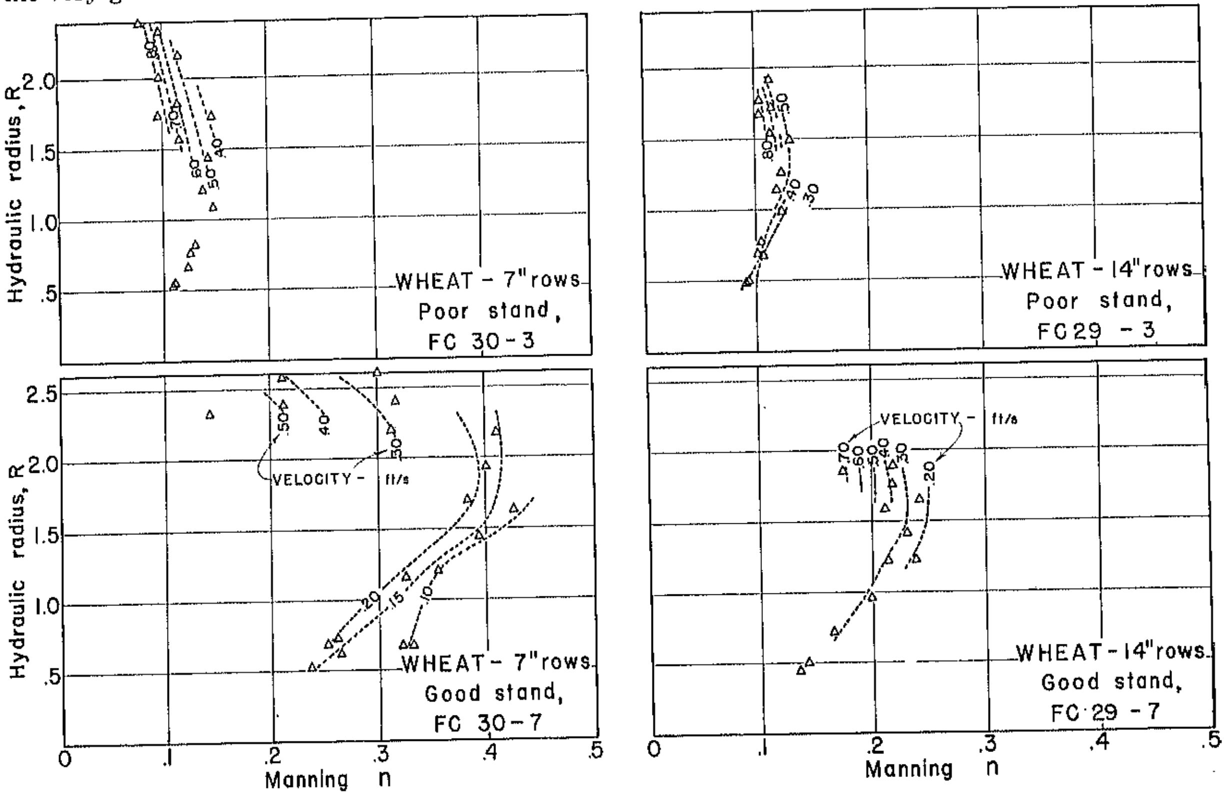

FIGURE 54.—Effect of row spacing and cover quality on retardance coefficients for wheat. (Compare horizontally for row spacing and vertically for cover quality.)

tered. However, when flow velocity is used as a parameter a family of isovels can be drawn through the field of points. These isovels show that, for a given depth as velocity increased, the Manning n value decreased. The isovels were well separated and well defined for the deeper flows but were less so for the shallower flows. In fact, for three of the four channels the isovels merge into one line for the small depths.

For the poor-quality stands there was little or no difference in the Manning n value for the 7-inch-row and 14-inch-row plantings. However, for the good-quality stands the n values for the 7-inch row spacing were considerably larger than the n values for the 14-inch row spacing. For example, if R=0.5 ft, the n value is 1.7 times greater.

Two row spacings (40 inches and 20 inches) were used for 'Hegari', a tall sorghum. The n-hydraulic radius curves (fig. 55) show a difference in n for the low flows, with the wider row spacing having the lower value, as expected. When the flow reached a hydraulic radius of about 1.5 feet, there was no difference between the two row spacings.

Influence of Row Direction on Friction Factor

Rows running parallel to the flow and perpendicular to the flow were tested for their effect on the friction factor for wheat. The row spacing was 7 inches in each case. For the higher flows, which submerged the vegetation, the n–VR curves show that row direction had no effect. A comparison of the n values in figures 17 and 20 for a VR value of 1 shows an n value of about 0.2 for each row direction. For the low flows a large difference was found in the n values, as shown by the n-hydraulic-radius curve in figure 56. Again the isovels

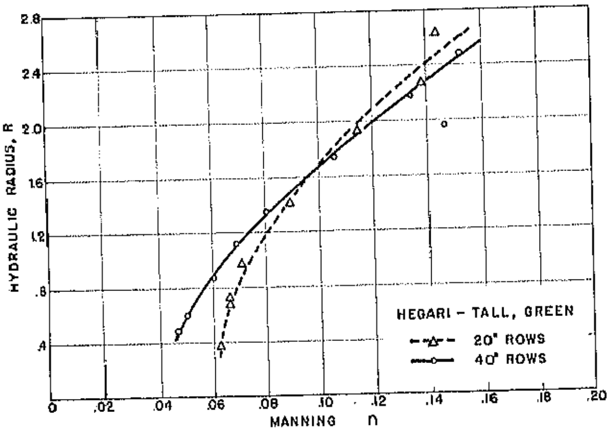

FIGURE 55.—Relation of Manning n to hydraulic radius (R) for channels planted to 'Hegari' sorghum.

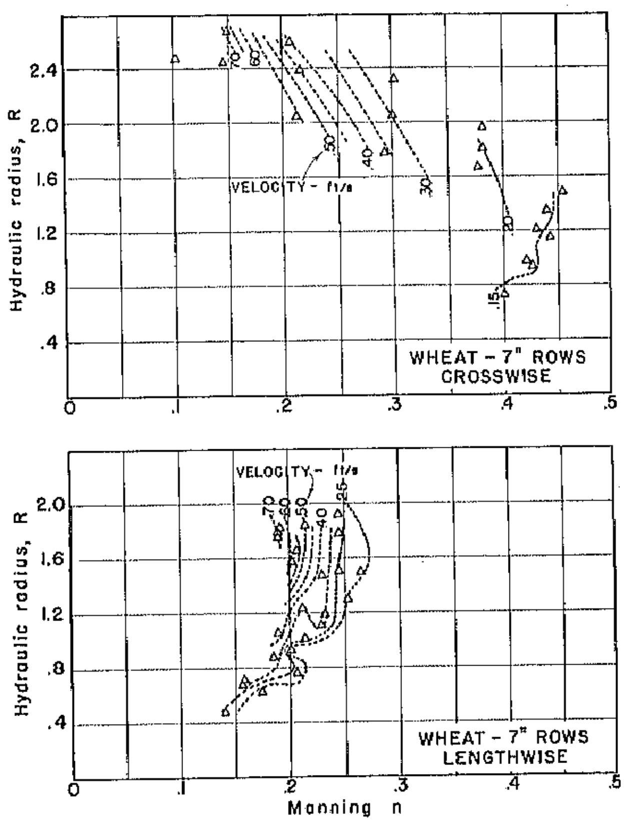

FIGURE 56.—Effect of row direction on retardance coefficients for wheat.

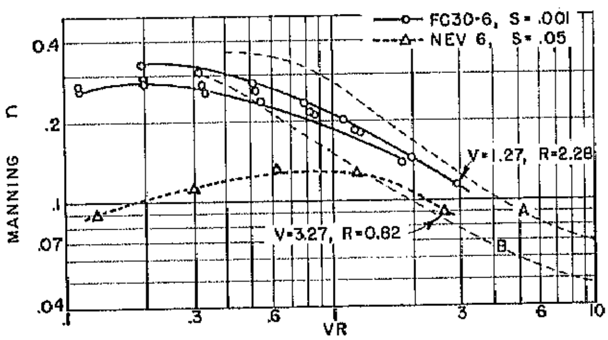

FIGURE 57.—Relation of Manning n to product of velocity and hydraulic radius (VR) for channels planted to sudangrass. (One set of envelope curves is for channel on 0.1-pct slope; the other curve is from test results on channel with a 5-pct slope.)

are shown. A comparison of n values at a hydraulic radius of 0.8 feet shows a value of 0.2 for the parallel (lengthwise) rows and 0.4 for the perpendicular (crosswise) rows. If the two graphs were superimposed it would be found that, at the greater hydraulic radii and velocities, the isovels merge, which is evidence of the equality of the n–VR relationship at the larger flows.

VALIDITY OF n-VR DESIGN METHOD

The n–VR design method presented in the "Handbook of Channel Design for Soil and Water Conservation" (cited in footnote 3) has proved to be a useful tool. However, there has been some concern on the part of those who developed this method that it was being used outside the intended range. The n–VR curves published previously have been obtained from studies on steep channels (generally a 3-percent slope or more). Thus, a large VR product is the result of a large V and a small R. These experiments gave us an opportunity to answer a burning question—if the relative values of the two quantities are changed, so that V is small and R is large (giving the same VR product as before), will the n value be the same? The tests on sudangrass were used in our attempts to answer this question. The results of tests on sudangrass in a small, steep (5-percent slope) channel were available for a comparison. The covers of both stands were somewhat alike, tall and green.

A comparison of the n–VR curves can be made from the graph in figure 57. For the larger VR values both retardance curves lie between curves A and B. Whether the difference between them is attributable to physical differences in the two stands or to the differences between velocities or depths is not known. At least the difference is not large, and some confidence is gained in the applicability of the n–VR method to situations where V is small and R is large.

* 1977-G.P.O.-1750-S/771-040/09